Recent Developments in Seedless Grapevine Breeding

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Grapes are one of the most commonly produced fruit crops in the world and are consumed as table grapes, wine grapes and dried grapes. In line with consumer demands, seedlessness continues to be an important feature that increases the chances of marketing grapes. Nearly all of the dried grapes that are offered to the world markets are seedless grapes. In addition, the demand for seedless varieties has increased steadily in the table grape trade over the years. Therefore, the production of new seedless grape varieties with large berries that are suitable for table consumption is one of the important goals of breeding studies in viticulture. In this study, recently bred and released new seedless grape varieties are briefly introduced, seedless grape breeding methods are summarised, and the latest developments in breeding methods are explained.

INTRODUCTION

Consumer demand for seedless grape varieties – both dried and table grapes – has been increasing worldwide. Almost all of the dried grapes consumed in the world markets consist of seedless grape varieties. In principle, seedlessness is produced in two mechanisms: through parthenocarpy and through stenospermocarpy. Seedless fruit set occurs without fertilisation and pollination in parthenocarpic fruit set (Perl *et al.*, 2000). Parthenocarpic grape varieties are not preferred in the market due to their small berry size, while stenospermocarpic varieties experience a greater demand due to both table fruit and dried fruit quality. In stenospermocarpic fruit set, fertilisation and pollination occur normally as in the case of seeded grape varieties. However, with genetically controlled mechanisms, the development of integuments in the ovules after pollination is prevented. As a result of degeneration of the embryo and then the endosperm, seed development stops, with only partially formed seeds or seed traces being left (Costantini *et al.*, 2008).

INHERITANCE OF SEEDLESSNESS

Different hypotheses have been proposed to determine the inheritance of seedlessness in grapevines. While some researchers have stated that seedlessness is controlled by recessive genes, another group of researchers has reported that it is controlled by different numbers of dominant genes (Constantinescu *et al.*, 1972, Spiegel-Roy *et al.*, 1990, Sato *et al.*, 1994, Ledbetter & Burgos, 1994). In recent years, the most accepted model for the inheritance of seedlessness is that seedlessness is controlled by three independent recessive genes that are regulated by a dominant gene named SdI (seed development inhibitor) (Bouquet & Danglot, 1996, Lahogue *et al.*, 1998, Adam-Blondon *et al.*, 2001, Doligez *et al.*, 2002).

SEEDLESS GRAPE-BREEDING METHODS

The breeding of seedless, colourful, disease-resistant new grape varieties with large berries is one of the important topics studied in viticulture. In addition to traditional methods such as clonal selection and conventional crossbreeding, biotechnological methods such as embryo rescue techniques and polyploidy have gained importance in seedless grape breeding. Furthermore, supportive genetic techniques, such as early selection with molecular markers in conventional crossbreeding, have also started to be used widely in seedless grape breeding (Değirmenci & Marasalı Kunter, 2007).

Conventional crossbreeding

In conventional crossbreeding studies on breeding seedless grape varieties, a seedless parent is used as the father (pollinator) and a seeded parent is used as the mother. However, in seeded x seedless crosses, the seedlessness rate obtained in the progeny is , varying between 0% and 49%, depending on the parental combination (Spiegel-Roy *et al.*, 1990). The successful culture of the abortive embryos of stenospermocarpic grapevine varieties has enabled seedless x seedless crosses in conventional crossbreeding studies. This practice (embryo rescue technique) has increased the rate of seedlessness observed in F_1 plants in seedless x seedless crosses, and the seedlessness rate in the progeny has ranged from 16.7% to 92%, depending on the parental combination (Ramming *et al.*, 1990). During the past 30 years, embryo rescue has been used mostly in seedless grapevine breeding

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programmes in the United States, Israel, South Africa, Chile and Australia. "Prime", "Mystery", "Spring Blush" and "Black-finger" are seedless table grape cultivars developed in Israel (Perl *et al*., 2003). Similarly, many studies have been published in the literature reporting the successful use of the embryo rescue technique in crossbreeding studies in viticulture (Ramming *et al*., 2000; Yang *et al*., 2007; Tian & Wang, 2008; Ji & Wang, 2013; Uquillas *et al*., 2013; Li *et al*., 2014, 2015).

Many seedless grape varieties obtained by conventional crossbreeding studies have been offered to the world grape market. The names of some of these table grape varieties and parental breeds are as follows: Autumn Royal (Autumn Black x Fresno C74-1; black), Beauty Seedless (Koenigin der Weingaerten x Black Kishmish; black), Crimson Seedless (Emperor x Fresno C33-199; Red-black), Fantasy Seedless (Fresno B 36-27 x Fresno C 78-68; black), Flame Seedless ((Cardinal x Sultanina) X (Red Malaga x Tifafihi Ahmer) X (Muscat of Alexandria x Sultanina); red), Ruby Seedless (Emperor x Sultana Moscata; red), Scarlet Royal (C33-30 x C103-41; red), Sunred Seedless (Datal x Ruby Seedless; red), Sweet Scarlet (C33-30 x C51-63; red), Superior Seedless (Cardinal x ? (seedless variety), white) (Julius Kühn Institute, 2018a).

Marker-assisted selection in crossbreeding

Since breeding by the conventional crossbreeding method requires a long time and high costs, studies on the development of selection with the help of DNA-based markers have gained importance in recent years. In this context, the segregation of seedless genotypes in the progeny obtained by the crossbreeding of seeded and seedless parents is performed with the help of molecular markers. Based on the hypothesis proposed by Bouquet and Danglot (1996), Lahogue *et al*. (1998) developed a codominant SCAR (sequence characterised amplified region) marker called SCC8, and it was successfully used for the segregation of seeded x seedless hybrid genotypes. In a study by Mejía and Hinrichsen (2003), the dominant SCAR marker, called SCF27, was used for selecting seedless progeny in Ruby Seedless x Sultanina hybrids.

Significant progress has been made in the development of molecular markers in grapevines over the past two decades. Linkage groups related to berry size and seedlessness in grapevines were detected in the quantitative trait loci (QTL) maps obtained from different seedless parental combinations (Doligez *et al*., 2002; Fanizza *et al*., 2005; Cabezas *et al*., 2006; Mejía *et al*., 2007; Costantini *et al*., 2007, 2008). Two of these were identified on linkage group 18 (LG18), and one on linkage group 4 (LG4) (Dai *et al*., 2011). Cabezas *et al*. (2006) developed a genetic map from the F1 combination obtained from the crossbreeding of the conventional, seeded *V. vinifera* variety "Dominga" and the seedless variety "Autumn Seedless". The QTL map indicated a large QTL region in the linkage group 18 associated with the seedlessness trait, and VMC7F2 was reported as the SSR marker closely associated with this QTL region. It was claimed that the VMC7F2 marker could be used in marker-assisted selection (MAS) for early detection of seedless individuals in breeding. Costantini *et al*. (2008) confirmed this finding after QTL analyses for berry size and ripening time in grapevines, and identified VMC7F2 as the most closely associated marker with the SdI locus. Followed by further research, papers have been published on the successful use of the VMC7F2 marker in breeding studies on seedlessness. Akkurt *et al*. (2012) found that the 198 bp allele from the VMC7F2 marker in the "Muscat Hamburg" x "Sultani" hybrid population was closely associated with seedlessness in the F1 generation and stated that it could be used for MAS in the early selection of seedlessness. Karaağaç *et al*. (2012) indicated that the 198 bp allele and the VMC7F2 marker could be used successfully in the selection of seedless individuals in segregations, and that the progeny size could be reduced to 54%.

Based on their study, involving sequence analyses, sequence characterisation and transcriptional analyses, Mejía *et al*. (2011) suggested that VvAGL11 was the major functional candidate gene in seedlessness. The researchers reported that VvAGL11 was the major locus for seedlessness in *Vitis vinifera* varieties, similar to AGL11 from the D-lineage MADS-box family responsible for seed development in different plant species, and developed a series of STS (sequence tagged site) markers associated with this gene. The P3-VvAGL11, which is one of the developed markers, was determined to be used effectively in the early detection of stenospermocarpic seedlessness in grapevines. Bergamini *et al*. (2013) used the VvAGL11 marker in the F_1 genotype of 475 seeded x seedless crosses and indicated that the marker can be used in all seedless phenotypes.

NEWLY BRED SEEDLESS GRAPE VARIETIES

There are a total of 67 seedless grape varieties that have been bred since 2000 and recorded in the VIVC database. Of these varieties, 66 are table varieties and one is a wine grape variety. Most of the varieties have been registered in the USA, followed by Turkey, Brazil, China, South Korea and South Africa. The bred varieties and their parents are presented in Table 1.

CONCLUSION

The primary traits on which the focus is in the development of new varieties in grapevine-breeding studies are seedlessness, berry size, high quality, resistance to diseases, earliness and lateness, and resistance to stress conditions. In addition to conventional breeding methods in seedless grape breeding, biotechnological approaches have gained importance in recent years. The use of *in vivo* growth-regulating agents, along with the embryo rescue method, has led to a significant improvement in the survival of abortive ovules.

Especially in seedless grape breeding, the use of genetic markers has gained great importance in its contribution to selection studies. Various researchers have reported that, while VMC7F2, one of the SSR markers, can be used successfully in the early selection of seedless varieties, the p3-VvAGL11 STS marker can be used more effectively in MAS. In this way, the long-term, labour-intensive and costly grapevine-breeding studies can be made shorter and more effective. While studies focusing on the development of new seedless varieties are concentrated mainly in the USA, Turkey, Israel, Italy and China, studies on developing

TABLE 1
Seedless grape varieties bred in the year 2000 and later (Julius Kühn Institute, 2018b).

Variety	Skin colour	Usage	Origin	Species	First parent	Second parent	Year of cross-breeding
Cengizbey	Black	Table	Turkey	*Vitis vinifera*	Ribol	Güz üzümü	2016
Gönülçelen	Red	Table	Turkey	*Vitis vinifera*	İtalia	Reçel üzümü	2016
Kebeli	White	Table	Turkey	*Vitis vinifera*	Ribol	Güz üzümü	2016
Özer Beyazı	White	Table	Turkey	*Vitis vinifera*	Ribol	Güz üzümü	2016
Süleymanpaşa Beyazı	White	Table	Turkey	*Vitis vinifera*	A. Beyazı	(Uşuvi X S. Çekirdeksiz)	2016
Arra eighteen	Black	Table	USA	*Vitis vinifera*	Grz 4	Gaw 6	2015
Brilliant Seedless	Red	Table	China	*Vitis vinifera*	Red Globe	Centennial Seedless	2012
Güz Gülü	Red	Table	Turkey	*Vitis vinifera*	Kırmızı Şam	Barış	2011
Tekirdağ Misketi	White	Table	Turkey	*Vitis vinifera*	İskenderiye Misketi	Sultani	2011
Arra thirty (Arra Sugar Drop)	White	Table	USA	*Vitis vinifera*	C.R.	Grapaes	2008
Arra twenty-eight (Arra Passion Punch)	Red	Table	USA	*Vitis vinifera*			2008
Candy Dreams	Black	Table	USA	Hybrid of *Vitis* species	Ifg 01161-040-184	Ifg 04025-037-112	2008
Arra twenty-five	White	Table	USA	*Vitis vinifera*	Gat 3	Gvz 6	2006
Arra twenty-nine (Arra Passion Fire)	Red	Table	USA	*Vitis vinifera*	A. 3	Gaw 5	2006
Arra twenty-two	Red	Table	USA	*Vitis vinifera*	A. 3	Je 1	2006
Candy Crunch	Black	Table	USA	Hybrid of *Vitis* species	Ifg 01032-067-222	Arkansas 2798	2006
Candy Hearts	Red	Table	USA	Hybrid of *Vitis* species	Is 283	Fantasy Seedless	2006
Candy Snaps	Red	Table	USA	Hybrid of *Vitis* species	Ifg 03003-074-251	Ifg 02089-081-217	2006
Sugar Crisp	White	Table	USA	*Vitis vinifera*	Ifg 02013- 090-033	Ifg 01034- 069-026	2005
Sugra thirty-eight	Red	Table	USA	*Vitis vinifera*	Sun World Seedling 98127-111-153	Sun World Seedling 94190-162-345	2004
Sugra thirty-five	White	Table	USA	*Vitis vinifera*	Sun World Seedling 97148-027-365	Sugra thirty-one	2004
Sweet Enchantment	Black	Table	USA	*Vitis vinifera*	Summer Royal	Regal Seedless	2004
Sweet Mayabelle	Red	Table	USA	*Vitis vinifera*	Ifg 01077-096-221	Ifg 01054-082-202	2004
Sweet Nectar	Red	Table	USA	*Vitis vinifera*	Ifg 01034-069-096	Ifg 01054-082-239	2004
Sweet Sapphire	Black	Table	USA	*Vitis vinifera*	Beitamouni	C 22-121	2004

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TABLE 1 (CONTINUED)

Variety	Skin colour	Usage	Origin	Species	First parent	Second parent	Year of cross-breeding
Isis	Red	Table	Brazil	Hybrid of *Vitis* species	Cnpuv 681- 29	LINDA	2004
Vitoria	Black	Table	Brazil	Hybrid of *Vitis* species	Cnpuv 681- 29	LINDA	2004
Green Angels	White	Table	Israel	*Vitis vinifera*	Aro 2117	Aro 1717	2004
Sweet Jasper	White	Table	Israel	*Vitis vinifera*	Aro 2117	Aro 1717	2004
Cotton Candy	White	Table	USA	Hybrid of *Vitis* species	Arkansas 2674	Princess	2003
Sweet Globe	White	Table	USA	*Vitis vinifera*	Usda Selection B31-164	Princess	2003
Sweet Surprise	Black	Table	USA	*Vitis vinifera*	Princess	Fantasy Seedless	2003
Zhaoxia Wuhe	Pink	Table	China	Hybrid of *Vitis* species	Jingxiu	Bronx Seedless	2003
Funny Fingers	Black	Table	USA	Hybrid of *Vitis* species	Calinda	Witch Fingers	2002
Sugra forty-one	White	Wine grape	USA	*Vitis vinifera*	Sun World Seedling 97035 209-287	Sun World Seedling 97029-206-141	2002
Arra nineteen (Arra Passion Glow)	Pink	Table	USA	*Vitis vinifera*	Gar 4	Gzr 1	2001
Arra sixteen	White	Table	USA	*Vitis vinifera*	Gv-45	Sultanina	2001
Arra two	Red	Table	USA	*Vitis vinifera*	Gaw 1	Gzw 5	2001
Jack's Salute	Red	Table	USA	*Vitis vinifera*	Red Globe	Princess	2001
Sugra thirty-six	Red	Table	USA	*Vitis vinifera*	Sun World Seedling 97001-198-219	Sun World Seedling 93018-070-024	2001
Sweet Celebration	Red	Table	USA	*Vitis vinifera*	Red Globe	Princess	2001
Sweet Favors	Black	Table	USA	*Vitis vinifera*	Autumn Royal Seedless	?	2001
Sweet Joy	Black	Table	USA	*Vitis vinifera*	Autumn Royal Seedless	?	2001
Sweet Romance	Red	Table	USA	*Vitis vinifera*	Autumn Royal Seedless	Crimson Seedless	2001
Sweet Secrets	Black	Table	USA	*Vitis vinifera*	Is 283	Fantasy Seedless	2001
Sweet Sunshine	White	Table	USA	*Vitis vinifera*	Princess	Regal Seedless	2001
Sweet Surrender	Black	Table	USA	*Vitis vinifera*	Summer Royal	Regal Seedless	2001
Joybells	Red	Table	South Africa	*Vitis vinifera*	Sunred Seedless	?	2001
Arra fifteen (Arra Sweeties)	White	Table	USA	*Vitis vinifera*	Gaw 5	Gzw 4	2000
Arra ten	Red	Table	USA	*Vitis vinifera*	Gar 4	Gzr 2	2000

TABLE 1 (CONTINUED)

Variety	Skin colour	Usage	Origin	Species	First parent	Second parent	Year of cross-breeding
Sheegene 1 (Kaylee seedless)	Red	Table	USA	*Vitis vinifera*	Red Globe	Princess	2000
Sheegene 2 (Timpson)	White	Table	USA	*Vitis vinifera*	Red Globe	Princess	2000
Sheegene 3 (Magenta)	Red	Table	USA	*Vitis vinifera*	Red Globe	Princess	2000
Sheegene 4 (Luisco)	White	Table	USA	*Vitis vinifera*	Red Globe	Autumn Seedless	2000
Sheegene 6	Red	Table	USA	*Vitis vinifera*	Red Globe	Princess	2000
Sheegene 9 (Melanie)	White	Table	USA	*Vitis vinifera*	Red Globe	Princess	2000
Sheegene 10 (Russel's pride)	Red	Table	USA	*Vitis vinifera*	Red Globe	Princess	2000
Sheegene 11	White	Table	USA	*Vitis vinifera*	Red Globe	Princess	2000
Sheegene 12 (Krissy)	Red	Table	USA	*Vitis vinifera*	Red Globe	Princess	2000
Sheegene 13 (Timco)	Red	Table	USA	*Vitis vinifera*	Red Globe	Princess	2000
Sheegene 14	White	Table	USA	*Vitis vinifera*	Red Globe	Autumn Seedless	2000
Sheegene 15	White	Table	USA	*Vitis vinifera*	Red Globe		2000
Sheegene 17 (Great Green)	White	Table	USA	*Vitis vinifera*	Red Globe	Princess	2000
Sheegene 18 (Kelly)	White	Table	USA	*Vitis vinifera*	Red Globe	Princess	2000
Sheegene 21 (Ivory)	White	Table	USA	*Vitis vinifera*	Red Globe	Princess	2000
Heukisul	Black	Table	Korea	Hybrid of *Vitis* species	Kyoho	Sultanina	2000
Sujeong	White	Table	Korea	Hybrid of *Vitis* species	Kyoho	Sultanina	2000

Note: Synonyms and trademarks are given in parentheses.

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new seedless varieties are ongoing in all countries involved in viticulture business in accordance with their economic priorities.

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