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PRODUCTION OF SEEDLESS WATERMELONS

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INTRODUCTION

Triploid (3X) hybrid watermelons, first produced by Kihara and Nishiyama in 1939 (3),¹ are a classical example of the use of colchicine-induced polyploids for the production of seedless fruit. Japanese scientists since then have tried continuously to perfect the technique and make it a commercial success (2, 4, 5, 6). Serious problems remain so that even in Japan, where labor and cost of seed production are cheaper than in the United States, commercial production of seedless hybrid watermelon has not expanded as much as expected. Several attempts have been made by certain State universities and seedsmen to popularize seedless watermelons in the United States, but they are still practically unknown on most consumer markets.

The U.S. Vegetable Breeding Laboratory (VBL) at Charleston, S.C., has worked on this problem since 1955 and three autotetraploid breeding lines, Tetra 1, Tetra 2, and Tetra 3, were released in 1962 to seedsmen, who were to undertake the production of triploid hybrid seed using suitable diploids (2X) such as VBL 59-1 and VBL 59-6 released at the same time. Seedsmen, with few exceptions, failed to respond to this opportunity, feeling that too many problems of seed production and market production remained unsolved to make the operation profitable.

Diploid hybrid watermelons have been promoted by some commercial seed producers at a high cost to farmers. Triploid hybrid seed are even more expensive than ordinary F₁ hybrid seed, but the product has more potential advantages. Only a few seedless triploid hybrids have been tested on the commercial market; these came from Japanese seed producers and from the American Seedless Watermelon Seed

¹ Italic numbers in parentheses refer to Literature Cited, p. 12.

Corporation, Goshen, Ind. This U.S. firm has persisted with some success in efforts to solve the production problems with triploid hybrids, and a few small centers of market production of seedless melons are beginning to appear.

Because seedless and semiseedless watermelons offer an entirely different level of consumer appeal (1), additional educational efforts are needed; therefore, basing our conclusions on work at the VBL, we examine here in some detail the various problems involved in commercial production of these special kinds of watermelon and suggest some practical solutions.

We hope to interest extension workers and others in a position to promote overseas markets for farm products because triploid and tetraploid (4X) watermelons have special qualities adapted to this use. Among other advantages, they have extra-hard rinds and extra-firm flesh, which contribute to less damage in shipment and longer quality maintenance for distant markets. Seedless fruit tend to keep longer, probably because of reduced enzymatic action in the flesh at the area of undeveloped seed. The disadvantages, which include low productivity and high cost of seed, are now partly solved and the way to better solutions seems near.

Previously, personnel at the VBL have sought to demonstrate to research workers and growers the special qualities of the tetraploid varieties of low seed content produced here, and some favorable response is beginning to appear. Tetra 2 melons are rated high in a few locations in India and the United States where they have been tried. Seedsmen, however, are reluctant to propagate a variety that has such a limited or unawakened demand. We here propose a method to combine the virtues of tetraploids and the virtues of triploid hybrids as consumer products, and indicate how seed of both can be produced simultaneously in the same field.

EXPERIMENTAL DATA

Production of Tetraploids

The creation of a tetraploid variety is a prerequisite to the production of seedless hybrids. While induction by colchicine in itself is comparatively easy and effective, the maintenance of tetraploid watermelon lines at a stable level is a required capability that must be proved experimentally. Strict vigilance is necessary to eliminate any chance occurrence of diploids that apparently caused the Japanese breeders some difficulty. The VBL tetraploids have been stable in this respect and behave as true varieties. Chance diploid fruit can be easily detected at seed extraction by the greater number of seed, their

smaller size, and distinctive pattern. A useful clue to recognizing a tetraploid fruit is the larger size of the blossom scar (areole) in relation to the smaller scar of a diploid fruit. Chance aneuploids cannot be distinguished by any specific characteristic, but are extremely rare.

The several tetraploid lines evolved at this Laboratory have been maintained at a fairly stable level by continuous mass selection. They contain approximately 150 seed per fruit compared with 600 to 900 in the diploid. This level of seed fertility has been built up through years of mass selection from earlier counts of about 75 seed per fruit. Higher fertility in autotetraploids is possibly related to lesser multivalent frequency in meiosis, which leads to reasonably true breeding behavior (6).

For our purpose, selection for seed content (higher fertility) should not increase the seed number to diploid levels but should stabilize it at fewer than 200 seed per fruit. Much lower seed content makes the cost too high from a seed producer's standpoint, and much higher content defeats the purpose from a consumer's standpoint. The VBL lines have close to the desired number of seed per fruit.

Excellent fruit quality consisting of firm flesh, deep color, and highly stable soluble solids content (12 and 13 percent) is characteristic of the VBL tetraploid lines. Attainment of superior fruit quality in semiseedless tetraploids is an important requisite for the production of high-quality seedless triploids.

A need for caution in the extraction of seed from tetraploid fruits is recognized. Fermentation of the pulp should be avoided; the reduction in tetraploid seed vitality due to fermentation seems well confirmed. High-pressure water jets used with appropriate screens will effectively separate seed from fresh pulp, and most seed producers have this equipment. In addition, we recommend that commercial producers of tetraploid (and triploid) watermelon seed subject the freshly extracted seed to a compression process before drying. Tetraploid seed often dries with areas of entrapped air and moisture, which a suitable pressing operation should help to reduce. The entrapped air and moisture in tetraploid seed is thought to have caused some of the early difficulties with seed vitality (O. J. Eigsti correspondence); it also interferes with the separation of viable and nonviable seeds where a flotation process or a wind drift process is used. This interference results in the loss of some good seed.

At the VBL we use an old-fashioned lard press to separate the juice from small lots of freshly extracted tetraploid seed and pulp. We first wash the fragmented pulp thoroughly with water to remove most of the sugar, then press, and then separate the cake to dry under a fan. The dried pieces are pulverized and the chaff is separated from

the seed by air drift. This procedure could also be adapted commercially. We have regularly obtained tetraploid seed of high germinability and longevity since adopting this technique. Seed viability or vitality also has been indirectly improved through years of selection where nonviable and weak seed were naturally eliminated.

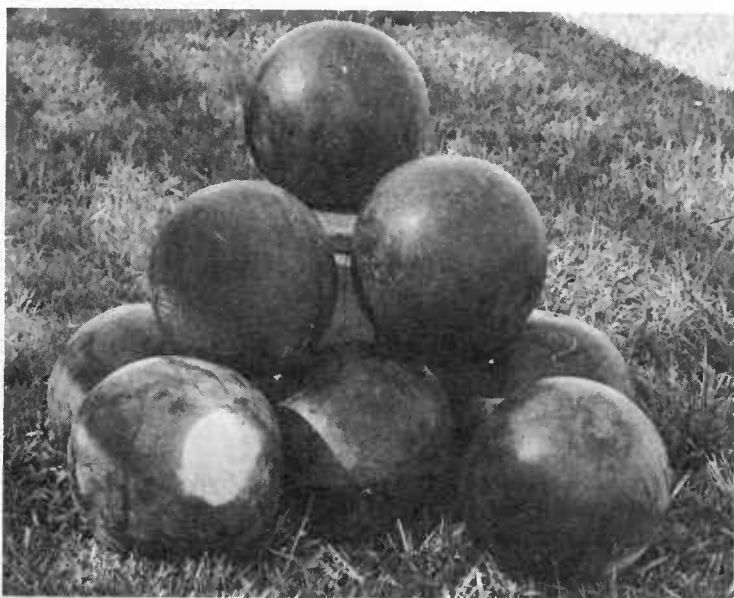
The size of tetraploid seed is considered important by some breeders because the size of empty ovules and locules in 3X fruit is thought to be large in proportion to the size of seed of the tetraploid female parent. This theory has not been fully confirmed. Some small-seeded tetraploids have been produced from small-seeded diploids and others have been selected from outcrosses, but it remains true that some large-seeded tetraploids germinate better and produce stronger seedlings.

We are currently recommending Tetra 1, Tetra 2, and Tetra 3 from the VBL, both as parents in the production of seedless hybrids and as stable varieties themselves with high consumer attributes (fig. 1). Tetra 1 and Tetra 2 are indistinguishable as varieties but perform differently as parents. From a seed producer's standpoint these all have sufficient productivity (2 fruits per plant) and sufficient seed content (150 per melon) to make seed production possible without excessive cost. Newer VBL tetraploids, such as W872 and W1068A, promise even better performance. Still other useful American tetraploid stocks are available from other breeders.

Production of 3X Seed

Production of triploid hybrid seed by the original and costly process of hand pollination of 4X x 2X parents must be rejected for practical reasons. Natural crossing by bee pollination in field plots seems the efficient answer to seed production, and various field designs of mixed plantings of tetraploids and diploids have been tried. Shimotsuma (6), in Japan, got best results with three tetraploid rows to one diploid row, whereas Wall (8), from the VBL, reported 83.6 percent triploids from natural cross-pollination with one tetraploid row to one diploid. The latter 1:1 design is in use at the VBL and seems to be suitable with 6-foot beds. If a 3:1 design is used, a greater proportion of 4X seeds will be produced by self-pollination. To insure higher proportion of 3X seeds, alternate (1:1) planting of 2X and 4X is desirable (fig. 2, A).

Outside (border) rows of diploid parent plants can be used for seed production but inside rows of diploid parent should be pulled immediately after pollination. This gives tetraploid plants more space to spread and prevents confusion of the two parental types of fruit at harvest.



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FIGURE 1.—Tetra 2 (top) and Tetra 3 (bottom), tetraploid (4X) watermelon varieties released to commercial breeders by the U.S. Department of Agriculture for use in the production of seedless hybrids, are themselves good consumer products. Tetra 1 (not shown), similar externally to Tetra 2, is an equally good product.

A, Generation for production of seed (2X, 3X, and 4X):

Plants	Rows ¹	Seed treatment ²
2X	//////////	Save seed to propagate 2X parent.
4X	XXXXXXXXXXXX	Save all seed from 4X rows.
2X	//////////	Remove these 2X plants after pollination.
4X	XXXXXXXXXXXX	Save all seed from 4X rows.
2X	//////////	Remove these 2X plants after pollination.
4X	XXXXXXXXXXXX	Save all seed from 4X rows.
2X	//////////	Save seed to propagate 2X parent.

B, Generation for production of melons for market (seedless and semi-seedless):

Mixed 3X and 4X plants	(X)(X)(X)(X)(X)(X)(X)(X)	Leave all fruit for single harvest.
	(X)(X)(X)(X)(X)(X)(X)(X)	3X plants produce medium-green melons, which are seedless. 4X plants produce light-green melons, which have few seed. 70 to 90% of the melons will be 3X; 10 to 30% of the melons will be 4X.
	(X)(X)(X)(X)(X)(X)(X)(X)	
	(X)(X)(X)(X)(X)(X)(X)(X)	
	(X)(X)(X)(X)(X)(X)(X)(X)	

¹ /// indicate 59-1, dark-green watermelons; XXX indicate Tetra 3, light-green watermelons; (X)(X)(X) indicate mixed 3X and 4X. These symbols have no significance as to number or spacing. They suggest an indefinite number of plants arranged in parallel rows.

² Seed from the 4X rows will be mixed 3X and 4X and can be sold or used to propagate the 4X parent. The 3X seed will not reproduce itself.

FIGURE 2.—Production of seedless watermelons: A, Generation for production of seed; B, generation for production of melons for market.

Thus far, seed harvested from 4X plants (arranged as in fig. 2, A) have proved to be approximately 33 percent 4X (sib-selfs) and 67 percent 3X (outcrosses). Attempts to separate the two kinds of seed before plantings have had only slight success. Kondo (4) and Shimotsuma and Matsumoto (7) presented a sorting method of diploids, triploids, and tetraploids on the basis of difference in thickness and weight of seeds, and O. J. Eigsti (letters on file) found differences in specific gravity of the three kinds of seed. But in commercial production, these differences do not lend themselves for practical use; seed characters have to be distinct enough for efficient separation in mechanical operations.

We recommend instead that the 3X and 4X seed be kept and sold as a mixture (fig. 2, B). This assumes not only that both the 3X and the 4X melons to be harvested will be marketable but also that they can be separated later on the basis of external characteristics.

In the absence of color markings, the 3X fruit can be distinguished from 4X with a high degree of accuracy by reference to its more triangular (lobed) shape when viewed from the blossom end. With some practice, this shape can be a highly reliable indicator.

In recommending that 3X and 4X seed be retained in their original mixture of 2:1 (fig. 2, *B*), we assume also that the 4X plants will be effective pollinators to cause fruit to set on the 3X plants. So far this assumption has been true in our experiments, provided there is no scarcity of bees. Elimination of the 2X pollinator in the market production stage is a key feature of this procedure because it greatly simplifies the routine for the grower.

Planting and Germination of 3X and 4X Seed

The erratic germination of 3X and some 4X seed is well known, and thus they should be germinated in flats or peat cups and then transplanted in the field. Germination data from two experiments are shown in table 1. Although transplanting will increase cost of production of seedless fruits, it also provides maximum economy of expen-

TABLE 1.—*Germination of 3X and 4X watermelon seed harvested in 1967 and tested in September 1969*

Experimental lots	Seed planted	Germination	
	<i>Number</i>	<i>Number</i>	<i>Percent</i>
W1083:			
3X (W987)-----	300	247	83
4X (Tetra 3)-----	300	249	83
Mixed (hand pollinated):			
3X-----	150}	197	66
4X-----	150}		
Mixed (bee pollinated):			
3X}	300	277	92
4X}-----			
W1084:			
3X (W985)-----	300	175	58
4X (Tetra 2)-----	300	172	57
Mixed (hand pollinated):			
3X-----	150}	167	56
4X-----	150}		
Mixed (bee pollinated):			
3X}	300	206	69
4X}-----			

sive seed and is a practice already widely used by market gardeners for other crops.

An attempt was made to compare direct seeding and transplanting with respect to stand and also to the proportion of 3X and 4X plants and fruit produced from the mixture. The population used was bee pollinated. The stand count data were too meager to report, but the harvest data are substantial and agreeably surprising (table 2). The proportion of triploid plants was not materially different in the two methods, but stand was better and the number of triploid fruits was greater in transplanted plots. We could not determine whether the selection pressure was in favor of 3X or of 4X plants when ungerminated and excessively weak seedlings were eliminated in transplanting. The agreeably surprising data that have come from these tests is the high proportion of survival of the 3X plants from the mixture of 3X and 4X seed and the high proportion of seedless (3X) fruit in the final harvest. The latter figure has sometimes exceeded 90 percent (table 2 and figure 3). Presumably, this predominance of 3X relates to a remnant of autosterility in the tetraploids.

Because transplanting seemed to be more efficient than direct field seeding, efforts were directed to find any seedling character that could be identified to separate 4X seedlings; for even though 4X plants are to be retained as pollinators, it might be helpful to separate the 3X and 4X in alternate rows for easier harvest separation. Initial observations indicate that plants with folded cotyledonary leaves may be up to 95 percent triploids (table 3), while the converse is not true; all plants with normal flat cotyledons are not necessarily tetraploids (tables 3 and 4). Hence, this seedling character, like the seed characters mentioned earlier, must be rejected as not sufficiently reliable.

TABLE 2.—*Proportion of 3X and 4X seedless watermelons harvested after bee pollination*

VBL No. and method of seeding	Melons harvested				
	3X		4X		Total
	Number	Percent	Number	Percent	Number
W1083:					
Direct seeded.....	94	79	24	21	118
Transplanted.....	183	90	20	10	203
W1084:					
Direct seeded.....	60	88	8	12	68
Transplanted.....	94	92	7	¹ 7	102

¹ 2X=1 melon: 1 percent.

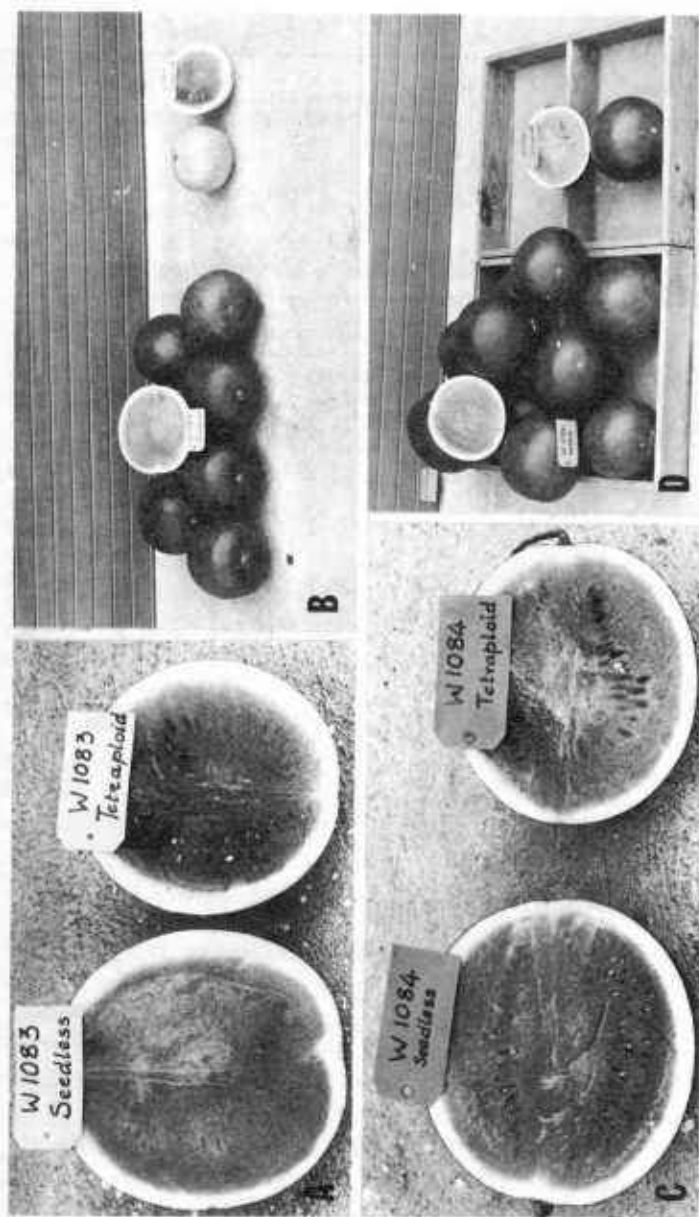


Figure 3.—A, Cut fruit of seedless (3X) and semiseedless (4X) watermelon component from bee-pollinated population W1083; B, seedless and semiseedless melons of W1083 in the proportion (7:1) in which they occurred at harvest; C, cut fruit of seedless (3X) and semiseedless (4X) component from bee-pollinated population W1084; D, seedless and semiseedless melons of W1084 in the proportion (10:1) in which they occurred at harvest. The 3X and 4X melons in W1083 are distinguishable by color, but those in W1084 are distinguishable only by shape viewed from the blossom end.

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TABLE 3.—*Proportion of 3X and 4X melons derived from plants with normal versus folded cotyledons*

Cotyledon shape	Hills	Melons harvested				
		3X		4X		Total
	<i>Number</i>	<i>Number</i>	<i>Percent</i>	<i>Number</i>	<i>Percent</i>	<i>Number</i>
Normal-----	50	56	72	22	96	78
Folded-----	50	71	97	2	3	73

TABLE 4.—*Folded cotyledons in relation to ploidy in watermelons*

VBL No.	Ploidy	Cotyledons				Total seedlings
		Normal flat	Doubtful class	Folded		
		<i>Number</i>	<i>Number</i>	<i>Number</i>	<i>Percent</i>	<i>Number</i>
W915A-----	2X-----	235	1	0	0. 1	236
W987-----	3X-----	81	6	24	21. 6	111
W1030-----	3X-----	63	7	20	22. 2	90
W1060-----	3X-----	68	12	98	55. 1	178
Tetra 2-----	4X-----	322	5	7	2. 1	334
Tetra 3-----	4X-----	324	3	2	0. 6	329
W872-R-----	4X-----	224	1	4	1. 8	229
W972-0-----	4X-----	177	20	12	5. 7	209
W1068A-9-M1--	4X-----	204	17	19	7. 9	240
W1083-----	Mix 3X and 4X.	198	8	31	13. 1	237
W1084-----	do-----	171	9	59	24. 6	239
W1111-----	do-----	155	9	65	28. 4	229

Production of 3X and 4X Melons and Their Quality

The 3X fruits do not develop parthenocarpically but must be stimulated by pollen. Apparently 4X pollen is just as effective as 2X pollen, but is less abundant; hence ample bees should be present. Provision for a diploid pollinator may be necessary for pollinating 3X flowers if bees are scarce and if there are not enough tetraploids in the mixture to meet the pollination requirements.

Distinction of 4X and 3X fruit (fig. 3, *A*, *C*) can be made in the field at harvest with the help of rind characters such as color in W1083 (fig. 3, *B*). Even when 4X and 3X fruit are similar externally (as in fig. 3, *D*), upon close examination, triangular conformation of 3X fruit is distinguishable from the more spherical conformation of 4X fruit.

The quality of 3X fruit in the VBL materials has been good; the

bad features sometimes found in 3X fruit, such as hollow heart, hard seed coats, large empty seed cavities, and brown seeds, have been found infrequently in the VBL materials. The melons have good eating quality, which can be appreciated by any discriminating consumer. Sweetness is notably higher and more stable than in the diploid parents. Seedsmen can choose any particular combination, depending upon whether striped or unstriped fruit, round or oblong shape, or large, medium, or small size is desired by consumers in any region. The smallest VBL triploid (fig. 3, *D*) is in the Sugar Baby size class, ranging from 9 to 17 pounds and averaging 11.7. At present (1970) a number of tetraploid lines have different rind characteristics and a suitable one, fulfilling the consumer preferences for certain external characters, can be chosen. Additional diploid parent pollinators need to be tested to provide distinguishing characters in the 3X fruit.

DISCUSSION

Insufficient disease resistance has been one of the limitations preventing the wide use of triploids. Tetraploid lines with wilt resistance incorporated are now produced at VBL and at Purdue University; also, many diploid parents like the VBL Wilt Resistant Congo carry wilt resistance. Hence, good wilt-resistant tetraploid and diploid lines are now available. Some of the newer breeding stocks like VBL W1068A also carry some measure of anthracnose resistance under field conditions. The polyploids seem even to have an extra degree of field tolerance to disease when compared with common varieties. Hence, lack of disease resistance need not be a deterrent for commercial production of seedless watermelons.

It is evident that some problems of production of seedless watermelons have been surmounted, but some still remain to be solved. What is needed today is an honest effort in the application of available findings. Though better solutions will be found, we need not wait for them before we make seedless watermelons available to the consumers. Consumers have long been accustomed to eating a particular kind of watermelon, like Charleston Gray of the East or Klondike of the West, and the time has now come to put a new kind on the market. Buyers would easily perceive and accept the excellent quality of properly produced seedless melons and would not grudge paying a few cents more per fruit.

Shipping agencies are not bothered by what is inside the fruit; they are concerned only with external features. The seedless and semiseedless melons would ship and keep well because they have extra-tough rinds and only a few seeds to provide loci for overripening. In fact, the Charleston triploids and tetraploids are so stable in internal flesh

quality that workers at the VBL leave these melons in the field for a single harvest.

Hence, for large-scale production and long-distance shipping, seedless and semiseedless melons will not suffer on any account by comparison with similar products. The cost of production will be higher and, like any new variety or novelty, these melons will tend to cost more initially. But unless a fair trial is given and repeated in many localities, growers will not be able to discern the small difficulties and improve the production techniques. According to M. Shimotsuna (personal communication), growers in Taiwan produce seedless watermelons on a large scale and ship them to markets in Hong Kong and Singapore, growers in Spain ship other kinds of melons to the United States, and growers in the Middle East ship melons to western Europe.

A better appreciation of production techniques and a change in the psychology of seedsmen, growers, shippers, and consumers could definitely bring a new future for seedless watermelons in the United States. We assume that growers are prepared to accept better quality and better market prices as a fair exchange for lower tonnage per acre and that a suitable balance of cost and reimbursement will be achieved. High yields also will be achieved after patient trial and effort.

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