Relationship between Fruit Shape and Seed Yield in *Cucurbita pepo*

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Cucurbita pepo is a very diverse species for fruit shape and size. The domestication of the species started thousands of years ago in North America from native small, round, usually bitter-flesh gourds. The initial use of these gourds by humans appears to have been consumption of the seeds, and thus the first steps of human selection were directed toward increasing fruit and seed size (1, 7). The fruit flesh could be consumed only after several cycles of boiling it to remove the bitter cucurbaticins. Subsequently, variants having non-bitter fruit were selected, resulting in the development of the pumpkins. The first pumpkins may have had a dual usage, for consumption of their seeds and consumption of their immature fruits, just as the land-race pumpkins inly Mexico and Guatemala do today. Later, selection for thicker, more starchy, and less fibrous fruit flesh allowed for consumption of the mature fruits, which today is the common culinary usage of pumpkins in the United States and Canada. The seeds, nonetheless, have some importance in economically developed countries as a high nutritive snack food and in the production of pumpkin seed oil (1, 6).

The great economic value of *C. pepo* today is based mainly on the culinary use of the young, immature fruits, often referred to collectively as summer squash. Summer squash deviate in shape from the roundness of their gourd and pumpkin ancestors (4). Selection has been geared toward deviation from the 1:1 length-to-width ratio in order to achieve a narrower, smaller volume of the soft placenta (endocarp). This resulted in the development of the flat (length-to-width ratio less than 1:1) scallop squash in North America prior to the European contact with that continent 500 years ago. After introduction of *C. pepo* to Europe, the culinary use of the young fruits began to be appreciated there. Selection for improved culinary traits occurred, most notably toward deviation from the 1:1 ratio in the direction of longer fruits, resulting in the development of the vegetable marrows (short, tapered cylindrical fruits), followed soon afterward by the cocozelles (long or very long, bulbous cylindrical fruits), and much more recently, by the zucchinis (long, uniformly cylindrical fruits) (5).

In a previous study (2) we tried to find relationships among fruit dimensions, seed cavity dimensions and seed yield in *C. pepo* ssp. *pepo*, which contains the Pumpkin, Vegetable Marrow, Cocozelle, and Zucchini cultivar-groups (5). In that work, we had included accessions that greatly differed in fruit weight and did not observe a consistent trend of seed yielding among these groups of cultivars. We decided to investigate further, this time using accessions that were more similar in fruit size. We chose 16 accessions, four from each of these four cultivar-groups (Table 1). We grew four replicates of four plants per accession at the Newe Ya'ar Research Center (northern Israel) in the summer season of 2000. Each plant was hand-pollinated to form 1-3 fruits/plant. The fruits were harvested 45 days past anthesis. Each fruit was weighed and then divided into three equal parts by length. The three parts will herein be referred to as the center, stylar end, and peduncular end. Each part was weighed and the seeds it contained were weighed and counted.

Mean fruit length (stylar end to peduncular end) increased and mean fruit diameter (equatorial) decreased in the order: pumpkin, vegetable marrow, zucchini and cocozelle (Table 2). The length-to-diameter ratio was a reliable parameter for differentiating among the four cultivar-groups.

The Pumpkin Group had more seeds per fruit than any other (Table 3). The Zucchini Group had the smallest seeds. The range of differences among cultivar-groups in seed number per fruit and in mean seed weight was 63 and 23%, respectively. The differences in the two seed-yield components resulted a clear differentiation of the four cultivar-groups in respect to seed yield. The Pumpkin Group had the highest yield, the Zucchini Group the lowest, and the Cocozelle Group and the Vegetable Marrow Group were intermediate.

Table 1. List of cultivar-groups, accessions, abbreviations, and origins.

Cultivar-group	Accession name	Abbreviation	Origin
Pumpkin	Cinderella	CIN	U.S.A.
Pumpkin	Early Sweet Sugar Pie	ESS	U.S.A.
Pumpkin	Porqueira	PRQ	Portugal
Pumpkin	Tondo Chiaro di Toscana	TOC	Italy
Vegetable Marrow	Beirut	BEI	Israel
Vegetable Marrow	Blanche non-coureuse	BNC	France
Vegetable Marrow	Long Green	LOG	U.K.
Vegetable Marrow	Verte Petite d'Alger	VPA	France
Cocozelle	Lungo Bianco di Sicilia	LBS	Italy
Cocozelle	Long Cocozelle	LCO	U.S.A.
Cocozelle	Lunga di Toscana	LUT	Italy
Cocozelle	Striato d'Italia	STI	Italy
Zucchini	Black Beauty	BBU	U.S.A.
Zucchini	Black Zucchini	BZU	U.S.A.
Zucchini	Nero di Milano	NER	Italy
Zucchini	Nano Verde di Milano	NVM	Italy

Table 2. Fruit dimensions in 16 accessions of *Cucurbita pepo*.

Cultivar-group	Cultivar	Fruit length (cm)	Fruit diameter (cm)	Length /Diameter
Pumpkin	CIN	14	19	0.71
Pumpkin	ESS	11	15	0.74
Pumpkin	PRQ	22	20	1.14
Pumpkin	TOC	11	17	0.69
Pumpkin	Mean	14	18	0.82
Vegetable Marrow	BEI	28	11	2.47
Vegetable Marrow	BNC	23	14	1.63
Vegetable Marrow	LOG	34	13	2.54
Vegetable Marrow	VPA	31	13	2.41
Vegetable Marrow	Mean	29	13	2.26
Cocozelle	LBS	41	8	5.02
Cocozelle	LCO	42	9	4.48
Cocozelle	LUT	49	11	4.60
Cocozelle	STI	61	10	6.37
Cocozelle	Mean	48	9	5.12
Zucchini	BBU	30	9	3.59
Zucchini	BZU	41	10	4.01
Zucchini	NER	40	10	3.88
Zucchini	NVM	39	11	3.48
Zucchini	Mean	37	10	3.74

Table 3. Seed yield per fruit and seed yield components in four cultivar-groups of *Cucurbita pepo*.

Cultivar-group	Cultivar	Seeds per fruit	Mean seed weight (mg)	Seed yield per fruit (g)
Pumpkin	CIN	372	68	25.30
Pumpkin	ESS	513	99	50.79
Pumpkin	PRQ	373	185	69.00
Pumpkin	TOC	247	128	31.62
Pumpkin	Mean	376	120	45.12
Vegetable Marrow	BEI	102	158	16.12
Vegetable Marrow	BNC	399	124	49.48
Vegetable Marrow	LOG	239	156	37.28
Vegetable Marrow	VPA	336	88	29.57
Vegetable Marrow	Mean	269	131	35.24
Cocozelle	LBS	303	94	28.48
Cocozelle	LCO	392	102	39.98
Cocozelle	LUT	211	171	36.08
Cocozelle	STI	267	163	43.52
Cocozelle	Mean	293	132	38.68
Zucchini	BBU	150	80	12.00
Zucchini	BZU	149	134	19.97
Zucchini	NER	191	129	24.64
Zucchini	NVM	429	85	36.46
Zucchini	Mean	230	107	24.61

Table 4. Seed yield distribution among the center, stylar end, and peduncular end in the fruits of four cultivar groups of *Cucurbita pepo*.

Cultivar-group	Cultivar	Seed yield (%) Stylar	Center	Peduncular
Pumpkin	CIN	25	42	32
Pumpkin	ESS	26	43	30
Pumpkin	PRQ	36	42	21
Pumpkin	TOC	31	58	10
Pumpkin	Mean	29	46	23
Vegetable Marrow	BEI	55	43	1
Vegetable Marrow	BNC	35	49	15
Vegetable Marrow	LOG	49	42	8
Vegetable Marrow	VPA	44	49	7
Vegetable Marrow	Mean	46	46	8
Cocozelle	LBS	70	29	0
Cocozelle	LCO	65	35	0
Cocozelle	LUT	88	12	0
Cocozelle	STI	89	10	0
Cocozelle	Mean	78	21	0
Zucchini	BBU	41	56	3
Zucchini	BZU	36	64	0
Zucchini	NER	41	56	3
Zucchini	NVM	49	47	3
Zucchini	Mean	42	56	2

The four cultivar-groups differed markedly in seed-yield distribution in the fruit (Table 4). In the Pumpkin Group, about half of the seed yield was produced in the central portion of the fruit, with about one-quarter of the yield each in the stylar and peduncular portions. In the Vegetable Marrow Group and the Zucchini Group, nearly all of the seed yield was produced in the central and stylar portions of the fruit. In the Cocozelle Group, over three-quarters of the seed yield was produced in the stylar portion, with none at all in the peduncular portion.

The results (Table 3) indicate that seed yield per fruit in *Cucurbita pepo* ssp. *pepo* has decreased over the course of history with highest yield in the most ancient type, the Pumpkin Group, and the lowest yield in the most modern type, the Zucchini Group. The decrease in seed yield per fruit is generally true also over the transition from round (pumpkin) to wedge-shaped (vegetable marrow) to long (cocozelle and zucchini) fruits, except that the Cocozelle Group, even though it has the longest fruits, produced a similar or higher yield than the Vegetable Marrow Group. This can be attributed to the bulbous stylar end of the cocozelles, in which nearly 80% of their seeds are produced. The dominant seed yield component which determined the differences in seed yield among cultivar-groups was the seed number per fruit. The pumpkins had the highest seed number and the most even distribution of seeds in the fruit. In the other cultivar-groups, there was a trend toward decreased seed number, especially in the peduncular end of the fruit. This phenomenon became increasingly apparent as the length-to-width ratio increased, quite consistent with observations made in cucumbers (3).

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