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Productivity of fennel (*Foeniculum vulgare* Mill.) genotypes in response to varying sowing time and row spacing under Punjab conditions

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Abstract

Fennel, known as 'Saunf' and belonging to the Apiaceae family, is primarily cultivated in Gujarat and Rajasthan, contributing over 90 % of India's fennel production. Fennel is mainly grown as a winter spice crop. A field experiment was conducted at the School of Organic Farming, Punjab Agriculture University, Ludhiana during the *rabi* seasons of 2020-21 and 2021-22 to evaluate the productivity of fennel genotypes under varying sowing times and row spacing. The experiment was laid out in split plot design comprising three fennel varieties (Ajmer Fennel-1, Ajmer Fennel-2 and Local), 2 sowing dates (November 1st and November 15th) and 2 row spacing (45 cm and 60 cm) with 3 replications. The variety 'Ajmer Fennel-2' (AF 2) recorded significantly higher branches and umbels per plant, while having a shorter plant height compared to 'Ajmer Fennel-1' (AF 1) and a local variety. The variety AF 2 also produced higher seed yields by 19.1 and 37.9 % than AF 1 and the local variety in 2020-21 and 13.6 and 44.4 % in 2021-22, respectively. The sowing of fennel on November 1st resulted in higher plant height, number of branches and seed yield as compared to November 15th sown fennel. Further, the sowing with row to row spacing of 45 cm recorded higher plant height, branches as compared to wider sown rows of fennel (60 cm), which contributed to higher seed yield during both the years. Thus, 'Ajmer Fennel-2' sown on November 1st with 45 cm row spacing performed best under Punjab conditions.

Keywords

fennel; productivity; row spacing; sowing time; varieties

Introduction

Fennel (*Foeniculum vulgare* Mill.) commonly known as *saunf* is an aromatic herb. It belongs to the family Apiaceae with diploid chromosome no. 2n=22. It is originated from Southern Europe and the Mediterranean region. India is the world's leading producer and consumer of spices, with fennel being among the most significant seed spices which covers an area of 82142 ha with a production of 137408 tons in 2022-23. Gujarat ranks first in both domestic and international fennel exports, with 47549 ha of cultivation and a production of 98272 tons (1). Rajasthan, Karnataka, Andhra Pradesh, Punjab, Haryana, Madhya Pradesh and Uttar Pradesh are the other fennel producing states in India. In north India, fennel is mainly grown in *rabi* season. It is used on a large scale in the pharmaceutical, cooking, confectionary and cosmetic industries. The whole plant of fennel has different uses such that the thick basal part of the leaf petiole is eaten as a vegetable, the young leaves are used in

seasoning food and the mature seeds are used for essential oil extraction and cooking (2). Fennel flowers, leaves and stems are used to produce brown and yellow dye.

To enhance the productivity of a crop, two primary strategies can be employed; implementing improved agronomic practices and selecting the new high-yielding varieties. With the growing demand for seed spices in limited cultivation areas, adoption of location specific and best suited production practices are crucial to maximize the yield per unit area of seed spices (3). The adoption of the high-yielding crop varieties along with improved agronomic management practices into new and nontraditional areas offers the most viable approach to enhance the crop productivity and increase the cost-benefit ratio for small-scale farmers (4).

The variation in sowing time *i.e*. beyond conducive environment either too early or delay in sowing for crops such as fennel can lead to drastic reduction of seed yield. Therefore, the timing of sowing is a critical factor that influences both growth and production. Optimizing the sowing schedule creates favourable environmental conditions that enhance plant physiological processes and helps in escaping the pests and diseases, thereby offering significant opportunities for higher yield (5). The choice of high-quality varieties with resistance to biotic and abiotic stresses plays a crucial role in enhancing crop yield. It was also reported from the past that early sowing of fennel improved the seed the yield, while a shortened duration of growth and development reduced the total dry weight of the plant due to decreased interception of radiation during the growth cycle of the crop (6). The plant spacing is a non-monetary input and a key factor to influence the fennel productivity. The wider spacing enhances the photosynthetic area and provides more sunlight while reducing competition among crop plants for nutrients, air and water. However, it also leads to a reduced plant population and yield (7). The optimal plant density that ensures plants are well-adapted to environmental conditions, such as water, air, light and soil and minimizes inter or intra-specific competition (8) results in better plant height, growth and yield of the crop.

Selecting superior genotypes resistant to both biotic and abiotic stresses is essential for achieving the higher crop yield. The resilient varieties are better suited to withstand changing climatic conditions, incidence of pests, diseases and adverse weather, which can otherwise affect crop growth and productivity. The cultivation of fennel requires careful consideration of factors such as sowing time and plant density to maximize the yield. By improving the cultivation practices to the specific needs of fennel, farmers can optimize their crop's potential and attain the higher yields.

To investigate the interactive effects of sowing date, spacing and varieties on the growth and yield of fennel in Punjab conditions, a field study was conducted at PAU, Ludhiana. There are numerous studies available on the individual effects of sowing dates, crop geometry and new varieties. However, the studies involving multiple factors combining the sowing dates, row spacing and new varieties altogether tested in a completely new environment are still lacking. Therefore, this study was aimed to identify the most appropriate time of sowing, row spacing and best variety in a new environment with respect to growth and productivity of fennel crop under irrigated conditions in Punjab.

Materials and Methods

Experimental site

The experiment was carried out at the research area of the School of Organic Farming, Punjab Agricultural University (PAU), Ludhiana, during the *rabi* season of 2020-21 and 2021 -22. The weather data for this period is summarized in Table 1. It is located at 30°54 N latitude and 75°56 E longitude, with an elevation of 247 m above sea level. The climate of Ludhiana is characterized as hot, humid and semi-arid, with temperatures gradually rising from April to June during the summer and becoming harshly cold in December and January. The temperature fluctuations are significant throughout the year, with summer temperatures often reaching 47 °C in the month of June and winter experiencing

Table 1. Weather data of experimental site during crop season in 2020-21.

Month	Temperature (°C)		Relative humidity (%)		Rainfall (mm)	Pan-evaporation (mm)	Sun shine (h)
	Max.	Min.	M	E			
November	25.3	9.8	90	34	15.6	52.8	5.9
December	19.4	7.1	92	52	6	38.2	5.1
January	16.9	7.1	94	65	11	31.6	3.0
February	23.8	10.2	93	54	17	49.6	7.0
March	29.5	14.9	82	37	5	118.1	6.7
April	34.2	16.9	59	20	14.3	192	8.4
May	36.3	22.6	56	32	37.3	235	7.9

Table 2. Weather data of experimental site during crop season in 2021-22.

Month	Temperature (°C)		Relative humidity (%)		Rainfall (mm)	Pan-evaporation (mm)	Sun shine (h)
	Max.	Min.	M	E			
November	26.8	10.7	91	32	0	54.8	6.9
December	20.7	6.7	95	49	0	34.3	4.9
January	15.7	8.4	94	73	113.4	30.2	2.3
February	21.1	8.5	91	50	43.5	53	7.3
March	30.8	15.9	87	38	0.8	109.4	9.2
April	39.0	20.5	57	15	0	206	9.6
May	39.2	26.1	49	27	25.6	254.4	7.4

frost with temperatures dropping close to 0 °C in the month of January. The rainfall is irregularly distributed, with the monsoon (July-September) accounting 75-80 % of total rainfall, while cyclonic disturbances mainly contributes to the winter rainfall.

Physical and chemical properties of soil

Prior to the start of the experiment, a composite soil sample from various parts of the experimental field was collected and analyzed for physical and chemical properties (Table 3).

Experimental design and treatments

The experiment was laid out in split plot design with 3 replications during both the years of the study. The experiment comprised of treatments including 2 dates of sowing (November 1st and November 15th), 2 row spacing (45 and 60 cm) in main plots and 3 varieties (Local, Ajmer Fennel 1 and Ajmer Fennel 2) in sub plots. The gross plot size for each plot was 18 m^2 (6.0 m × 3.0 m) during both the years.

Cultural practices

To ensure adequate soil moisture at the time of sowing, a pre-sowing irrigation was applied. The field was prepared for sowing by ploughing twice with disc harrow, followed by a cultivator and planking. The fennel variety 'Ajmer Fennel 1', 'Ajmer Fennel 2' and Local were sown as per the treatments. The recommended quantity (as per package of practices of Punjab) of nutrients, 20 kg N (45 kg urea) was applied in 3 equal splits; first at sowing, 3 weeks after sowing and 6 weeks after sowing. The crop was sown 3-4 cm deep by kera method using a seed rate of 10 kg ha^{-1} with row spacing of 45 and 60 cm (according to the treatments) on 1st and 15th November. One month after sowing, the plants were thinned to maintain a 10 cm plant to plant spacing. The irrigations were applied as per need. During both the years, weeds were controlled through pre-emergence application of pendimethalin at 0.75 kg ha^{-1} with 500 L of water followed by one hand weeding with wheel hand hoe at 45 days after sowing.

Field observations

The data on plant height, branches and umbels were recorded from 5 randomly selected plants from each plot at harvest and expressed as average per plant. At physiological maturity stage, when the plants had dried up and the umbel changes its colour from green to light yellow, the crop was harvested from a net plot area of 5.0 m x 2.4 m (for 60 cm spacing) and 5.0 m x 2.25 m (for 45 cm spacing). The crop was harvested in the first week of May during both years. Prior to manual threshing, the harvested crop was carefully packed in bundles and labelled accordingly. The seed yield was measured by collecting the plants from the net plot area, separating the seed from the straw through threshing, and cleaning the seed thoroughly. Finally, the seed and straw yield was expressed as quintal per hectare (q ha^{-1}).

Oil content and oil yield

The oil of fennel was extracted using Clevenger's apparatus. Initially, 250 g of fresh seed was carefully placed in the flat-bottomed flask with a capacity of 5 L. The flask was filled with water to half of its level. Then, the temperature was set at 100 °C for the initial 30 min. Once the boiling began, the temperature was reset to 60 °C and heating was continued for 3 hours and 30 minutes to ensure complete extraction of oil. The oil so obtained from the samples was expressed as percent of oil. Oil yield was calculated as the product of oil content (%) and seed yield (Kg ha^{-1}) for different treatments and expressed as L/ha.

Table 3. Soil physicochemical properties of experimental field in Ludhiana.

Property	2020-21	2021-22
Soil texture	Loamy sand	Loamy sand
pH	7.3	7.7
Electrical conductivity (dS m^{-1})	0.14	0.13
Organic carbon (%) by Walkley and Black's rapid titration method (15)	0.26	0.29
Alkaline $KMnO_4$ hydrolysable N (kg ha^{-1}) (16)	118.9	124.2
'Olsen's P (kg ha^{-1}) (17)	19.1	21.3
Ammonium acetate extractable K (kg ha^{-1}) by method using flame photometer (18)	158.5	155.7

Table 4. Effect of date of sowing and crop geometry on growth of different genotypes of fennel at harvest.

	Plant height (cm)			Branches/plant			Umbels/plant		
Date of sowing	**2020-21**	**2021-22**	**Mean**	**2020-21**	**2021-22**	**Mean**	**2020-21**	**2021-22**	**Mean**
Nov 1	152.9	153.9	153.4	10.3	8.8	9.6	15.8	19.9	17.9
Nov 15	140.7	148.6	144.6	9.0	7.5	8.2	14.7	16.7	15.7
LSD (0.05)	4.0	3.4	3.32	0.92	0.32	0.58	NS	1.2	0.80
Row Spacing (cm)									
45	147.8	150.1	148.9	9.4	8.1	8.8	15.1	18.8	16.9
60	145.9	152.4	149.1	9.9	8.0	9.0	15.4	17.9	16.6
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	0.75	NS
Variety									
Local	150.0	149.7	149.8	9.3	7.7	8.5	15.1	18.4	16.8
AF1	148.7	154.3	151.5	10.0	7.8	8.9	15.4	18.0	16.7
AF2	141.7	149.8	145.8	9.6	8.9	9.2	15.3	18.5	16.9
LSD (0.05)	2.8	NS	2.3	NS	0.38	0.48	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS

All data were compared using the analysis of variance method with the normal B x C

Statistical analyses

The CPCS1 software, which was developed by the Department of Statistics at Punjab Agricultural University (9), Ludhiana, India, was used to analyze the data. All comparisons were conducted at a significance level of 5 % (10).

Results

Plant height

The time of sowing of fennel crop significantly affected the plant height in both the years of the study. The crop sown early recorded significantly higher plant height (152.9 and 153.9 cm) as compared to late sown crop (140.7 and 148.6 cm) during 2020-21 and 2021-22 respectively. The variation in row to row spacing did not show any significant effect on the plant height during both the years. However, the different varieties responded differently in both the years of study. The plant height of AF 1 and local variety was significantly higher than the variety AF 2 however; all the varieties (AF 1, AF 2 and local variety) recorded statistically similar plant height without showing any significant differences during the second year of study.

Branches per plant

The crop sown on November 1st recorded significantly higher number of branches per plant as compared to delayed sowing (November 15th) and resulted in 14.4 and 17.3 % increase in branches per plant during 2020-21 and 2021-22 respectively. On the basis of the mean of 2-year study, November 1st sown fennel recorded 17 % higher branches as compared to November 15th sown crop. The crop sown either on 45 or 60 cm row spacing proved equally good in terms of producing number of branches per plant as the differences were statistically non-significant during both the years. However, the varietal differences recorded significant effects on number of branches per plant during the year 2021-22 only. The variety AF 2 produced 14.1 and 15.6 % higher branches than AF 1 and local variety. Further, 2 years means also recorded superiority of AF 2 over other varieties for producing more number of branches.

Umbels per plant

The early sown fennel (November 1st) recorded higher umbels per plant over late sown fennel (November 15th) during both the years of study. However, the difference was significantly higher during the second year of study and also on basis of the mean of 2 years study. The early sowing of fennel resulted in 19.2 % higher umbels than late sowing during 2020-21. Further, on the basis of mean of 2 years study, November 1st sown crop recorded 14.1 % higher umbels per plant. The crop sown with row to row spacing of 45 cm recorded significantly higher umbels per plant over 60 cm row spaced crop during the second year of study only. The performances of all the varieties in terms of umbels per plant were comparable to each other during both the years as the differences were statistically non-significant.

Seed yield

The fennel crop sown on November 1st recorded significantly higher seed yield as compared to late sown crop (November 15th) in both the years of study. The early sown crop had a seed yield higher to the tune 13.3 % in the first year, 16.1 % in the second year and 14.8 % on the basis of mean of 2 years. The crop sown with 45 cm row to row spacing recorded significantly higher seed yield over wider sown crop (60 cm). The comparatively narrow row spaced (45 cm) crop recorded 27.2 and 18.4 % higher seed yield than wider row spaced crop during 2020-21 and 2021-22 respectively. Similarly, the mean of the 2 years study, seed yield under narrow row spacing was 22.9 % higher than wider row spaced crop. Among varieties, Ajmer Fennel 2 has shown its superiority in terms of seed yield over Ajmer Fennel 1 and local variety during both the years of study. The variety AF 2 consistently outperformed other varieties by producing significantly higher seed yields in both 2020-21 and 2021-22, as well as on the basis of mean of 2 years. The variety AF 2 recorded 19.1 and 13.6 % higher seed yield as compared to AF 1 during 2020-21, 2021-22 respectively. It also outperformed the local variety by 37.8 % in 2020-21 and 44.4 % in 2021-22. The interactive effects of varieties and row spacing showed that the combination of variety AF 2 with 45 cm row spacing resulted in the highest seed yield of 13.60 q ha^{-1}; significantly higher than all other combinations (Table 6).

Table 5. Effect of date of sowing and crop geometry on seed and straw yield of different genotypes of fennel

	Seed Yield			Straw yield (q/ha)		
Date of sowing	**2020-21**	**2021-22**	Mean	**2020-21**	**2021-22**	Mean
Nov 1	11.9	10.8	11.36	65.1	63.1	64.1
Nov 15	10.5	9.3	9.89	61.4	59.2	60.3
LSD (0.05)	1.13	0.82	0.46	2.9	2.1	2.3
Row Spacing (cm)						
45	12.6	10.9	11.72	64.6	62.2	63.4
60	9.9	9.2	9.53	61.9	60.1	61.0
LSD (0.05)	1.13	0.82	0.46	NS	NS	2.3
Variety						
Local	9.5	8.1	8.81	63.6	61.1	62.4
AF1	11.0	10.3	10.69	65.4	64.0	64.7
AF2	13.1	11.7	12.38	60.7	58.3	59.5
LSD (0.05)	0.90	0.78	0.48	NS	2.9	3.2
Interaction	NS	NS	B×C =0.67	NS	NS	NS

All data were compared using the analysis of variance B x C normal

Table 6. Interactive effects of row spacing and varieties of fennel on seed yield (mean of 2 years).

	Varieties			
Row spacing (cm)	**Local**	**AF 1**	**AF 2**	**Mean**
45 cm	9.43	12.12	13.60	11.72
60 cm	8.18	9.26	11.15	9.53
Mean	8.81	10.69	12.38	
LSD (0.05)		0.67		

Straw yield

The fennel crop sown on November 1st recorded significantly higher straw yield as compared to late sown crop (November 15th) in both the years of study. The early sown crop recorded 6.1, 6.6 and 6.3 % higher straw yield over late sown crop during the first year, second year and on the basis of mean of 2 years respectively. The crop sown using either 45 or 60 cm row spacing recorded statistically similar straw yield as the differences were statistically non-significant during both the years. However, on the basis of mean of two years, crop sown with 45 cm row to row spacing resulted in 3.93 % higher straw yield over wider spaced sown crop. The variety AF 1 outperformed both AF 2 and the local variety in terms of straw yield during both the years and on the basis of mean of two years study also. The increase was 2.8 and 4.8 % higher than that of local variety during 2020-21, 2021-22 and 7.74 and 9.7 % over AF 2 during 2020-21, 2021-22 respectively.

Oil content and Oil yield

Oil content is an important feature of variety for its general, commercial and industrial purpose. The alteration in sowing time did not show any significant difference in oil content of fennel seeds during both the years. Further, change in row spacing also could not make any significant difference on oil content during both the years of study. However among different varieties, AF 2 recorded significantly higher oil content over local variety in the second year and mean oil content of 2 year study.

The oil yield (Table 7) revealed that early sown crop (November 1st) has higher oil yield in both the years of study. The November 1st sown crop recorded 9.5 % higher oil yield than that of November 15th sown crop in the first year and it further increases to 22.96 % during second year of study. Similarly, on the basis of 2 year mean, the early sown fennel crop recorded significantly higher oil yield (15.8 %) over late sown crop (November 15th). Unlike, oil content, the fennel crop sown at a narrower spacing of 45 cm compared to the wider spacing (60 cm) recorded significantly higher oil yield in both years of the study. The increase was 36.3 and 22.1 % higher during 2020-21, 2021-22 respectively. The oil yield, which depends on both oil content and seed yield, recorded the same trend across different varieties as it follows in the seed yield. The variety AF 2 recorded 15.4 and 26.5 % higher oil yield as compared to AF 1 during 2020-21, 2021-22 respectively. Similarly, it further increased over the local variety, by 45.6% in 2020-21 and 69.6 % in 2021-22. The interaction between varieties and row spacing revealed that AF 2, sown with 45 cm row spacing, recorded the highest oil yield of 23.35 L ha^{-1}, significantly surpassing all other combinations (Table 8).

Table 7. Effect of sowing dates and crop geometry on oil content and oil yield of different genotypes of fennel.

	Oil content (%)			Oil yield (L/ha)		
Date of sowing	**2020-21**	**2021-22**	**Mean**	**2020-21**	**2021-22**	**Mean**
Nov 1	1.56	1.63	1.59	18.77	17.83	18.3
Nov 15	1.63	1.55	1.59	17.11	14.50	15.8
LSD (0.05)	NS	NS	NS	NS	0.86	1.5
Row Spacing (cm)						
45	1.65	1.61	1.63	20.70	17.76	19.2
60	1.54	1.58	1.56	15.18	14.55	14.9
LSD (0.05)	NS	NS	NS	2.45	0.86	1.5
Variety						
Local	1.52	1.48	1.49	14.49	12.01	13.3
AF1	1.65	1.55	1.61	18.27	16.10	17.2
AF2	1.61	1.75	1.68	21.10	20.37	20.7
LSD (0.05)	NS	0.10	0.11	2.15	1.43	1.26
Interaction	NS	NS	NS	NS	B×C =2.02	B×C =1.78

All data were compared using the analysis of variance method with the least significant difference test at $p<0.05$. LSD least significant difference, NS non-significant, Nov November, AF1 Ajmer Fennel 1, AF2 Ajmer Fennel 2 B×C row spacing × varieties

Table 8. Interactive effects of row spacing and varieties of fennel on oil yield (mean of 2 years).

	Varieties			
Row spacing (cm)	**Local**	**AF 1**	**AF 2**	**Mean**
45 cm	14.38	19.97	23.35	19.2
60 cm	12.13	14.42	18.08	14.9
Mean	13.30	17.20	20.70	
LSD (0.05)		1.78		

Discussion

The early sowing of fennel (November 1st) benefited the crop with longer growing period which might have lead to taller plants than that of November 15th sown crop. The optimal temperature (Table 1) during the initial stages of growth might also have helped the healthy development and longer day light hour's helped boost the plant photosynthesis (11). The crop sown on November 15th faced immediate exposure to comparatively low temperatures in December which could have contributed to slower growth and short height of the plants. Additionally, the early sown fennel might have had an advantage to early access of soil nutrients and less competition from weeds and other plants, resulting in the healthier growth of the plant (12). The findings of the study also suggest that the shorter growth period associated with late sowing might have hindered the plants from fully utilizing the available resources in the present study. The plant height was higher in narrow spaced (45 cm) fennel crop. This might be due to the increased activity of growth hormone due to deficiency of light along with genetic characters of the variety (13). Among different varieties, AF 2 maintained its low plant height in both the years. The constraint of shorter growth duration limited the plants' ability to develop a robust vegetative structure (depicted in the plant height), including a reduced number of branches and leaf area which might have led to lower the photosynthetic capacity; diminishing the energy supply for reproductive development. As a result, the formation of umbels and seeds per umbel was compromised, resulting in the lower number as compared to crop sown earlier (November 1st). Fennel, being a winter season crop when experienced the shorter initial growing period might have caused it to enter the reproductive phase quickly due to rise in temperature and sunshine hours from February onwards. This limited the time available for umbel development, resulting in fewer umbels per plant and negatively impacting the overall yield and productivity of the crop in the present study. Apart from this, past studies have revealed that interaction of low temperatures along with shorter daylight hours can affect pollination and hinders the flower development (14).This means the plants may not produce as many umbels as early sown crop. In addition, the late sowing can result in nutrient deficiencies, impacting the final yield of the crop. The wider spacing between rows (60 cm) in fennel reduced the number of plants per unit area, which was reflected in the low seed yield. Among different varieties, AF 2 having vigorous growth in terms of profuse branching as well as better umbel formation proved its superiority over AF 1 and local variety in Punjab conditions.

The reduced seed yield also led to lower the oil yield, as oil yield is calculated by multiplying the oil percentage with seed yield. On the other hand, narrow spacing (45 cm) increased the plant population per unit area thereby resulting in a higher overall seed yield. This higher seed yield positively impacted the oil yield per unit area. In addition to higher seed yield of AF 2, its higher oil content (genetic character) also contributed to significantly higher oil yield over other varieties (AF 1 and local variety) which further confirmed its suitability of cultivation in Punjab. The interaction effects between row spacing and varieties revealed that the plant vigour and growth of AF 2 can be best accompanied with row to row spacing of 45 cm as sowing of this variety at 45 cm spacing proved to be the most effective than other combinations by producing the highest seed yield.

Conclusion

For raising fennel crop early in the season, especially the variety AF 2, performed better growth and significantly higher seed and oil yield as compared to delayed sowing (November 15th). Further, comparatively narrow spacing (45 cm) proved optimum as it resulted in better growths which led to its significantly higher seed and oil yield. So the variety AF 2 especially sown with row spacing of 45 cm would be an ideal option for farmers to achieve higher productivity under Punjab's conditions.

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Authors' contributions

RK planned and conducted the experiment, participated in data collection and drafted the manuscript. VP was involved in conducting the experiment, data collection and review of literature and performed the statistical analysis. RK and VP reviewed, edited the manuscript and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors do not have any conflict of interests to declare

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