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Diversity, foraging behaviour of floral visitors and pollination ecology of fennel (*Foeniculum vulgare* Mill.)

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Abstract

A study on floral visitors of fennel (*Foeniculum vulgare*) conducted at Karnal (Haryana) indicated that 39 species visited the crop among which, hymenopterans (47.1%) and dipterans (50.3%) were the most prominent groups. Six Apoidea species contributed 39.5% of the total visitors and Italian honeybee, *Apis mellifera* was the most prominent species (32.5%). Among the dipteran species, *Episyrphus balteatus* was the most prominent species (24.7%). *A. mellifera* was most abundant with 15.7 bees m^{-2} observation $interval^{-1}$ followed by *E. balteatus* (11.9 bees m^{-2} observation $interval^{-1}$). All the *Apis* species started foraging late (09.00 h) and *A. mellifera* had longer foraging period (spread up to 18.00 h), whereas, *A. cerana* foraged up to 16.00 h and *A. dorsata* till 14.00 h. Peak activity of dipterans and other hymenopterans was during morning and late afternoon hours. Bee-Q application increased Apoidea population by 29.1%, other hymenopterans by 12.6% and had no effect on dipteran population (3.0%). Mean seed yield of fennel in caged plots was 5.2 g $plant^{-1}$ compared to 29.7 g $plant^{-1}$ in open pollinated and 26.6 g $plant^{-1}$ in bee pollinated crop (an increase of 474.7% and 413.5%, respectively). Bee-Q treated plots gave the highest yield of 33.8 g $plant^{-1}$ (increase of 553.4%). Yields in bee pollination were at par with open pollination signifying the role of insect pollinators other than honeybees, especially dipterans like *E. balteatus, Eristalis arvorum*¸ *Eristalis* sp. and *Musca* sp.

Keywords: fennel, floral visitors, *Foeniculum vulgare*, pollination.

Introduction

The flowers of fennel (*Foeniculum vulgare* Mill.: Umbelliferae) are umbelliferous and hermaphrodite with a few staminate ones but protandrous condition necessitates cross-pollination. The crop is highly entomophilous with only 45%–52% fruit set due to self pollination (Shilova 1972). Honey bees (*Apis cerana* F., *A. florea* F. and *A. mellifera* L.) and syrphid flies are the most common pollinators (Youngken 1956; Narayana *et al*. 1960; Sagar 1981; Baswana 1984; CCS HAU 2000, 2001; Chaudhary *et al.* 2002). Caged plants produced few or no seeds compared to well set seeds in open pollinated (OP) plants (Youngken 1950, 1956). Bee pollinated plants gave twice the yield compared to plants in caged plots (Youngken 1956; Narayana *et al*. 1960; Sagar 1981; Baswana 1984). Sihag

(1986) reported that caged and open pollinated plants yielded 392 and 1364 seeds plant^{-1} and 3.4 and 9.6 g plant^{-1}, respectively; however, 1000 seed weight from caged plants weighed 8.8 g compared to 7.2 g from OP plants.

Except for the preliminary work of Sagar (1981), Baswana (1984) and Sihag (1986), no work has been reported on pollination ecology of fennel from India. The present study was initiated to investigate the abundance, diversity, temporal distribution and foraging behaviour of floral visitors with special reference to the bee attractant, Bee-Q in the north-western sub-tropical tract of India as a prerequisite to frame pollination strategies for the crop.

Materials and methods

The study was conducted at Regional Research Station, CCS Haryana Agricultural University, Karnal (Haryana) (29°43′ N latitude, 76^0 58′ E longitude, 245 m above MSL) on fennel cultivar HF-33 planted during the second week of October on ridges at 40 cm x 20 cm spacing following recommended horticultural practices (CCS HAU 1998) for 2 years during 1998–99 to 1999–2000.

Twenty five floral buds were tagged and timings (in day hours) of different floral events like flower opening, expansion of petals, visibility of anthers, dehiscense, shedding of petals and colour change of floral parts were recorded at 2-hourly intervals (Dafni 1992). Insect visitors on fennel were collected by sweep netting using cone type hand net throughout the crop blooming period. The collected insects were killed, preserved and identified by comparing them with the reference collection maintained at the Apiculture Laboratory, Regional Research Station, Karnal. The relative abundance of insect visitors was studied under two conditions namely, natural conditions or open pollination (OP) and in plots where the bee attractant Bee-Q was applied. Bee-Q, a bee food attractant, manufactured by M/s Custom Chemicides, USA, and marketed by Excel Industries Ltd., Mumbai, available in wettable powder form was sprayed @ 17 g l^{-1} of water using 200 l spray solution directed towards the umbels. Spraying was done in the morning at 20% flowering stage. Observations were recorded in 1 m^2 bloom area for 2 min (replicated thrice) at hourly intervals from 06.00 h till 18.00 h for 10 calm, clear and sunny days.

The effect of different modes of pollination (MOP) on fennel fruit yield was investigated using four modes namely, without insect pollination (WIP), bee pollination (BP), open pollination (OP) and Bee-Q. In WIP, the plants were caged in nylon nets and the crop was sprayed with endosulfan 35 EC (0.07%) to kill all the insects inside the cage to exclude their contribution towards pollination. In BP, a four-frame *A. mellifera* colony first kept in the centre of fennel field just at the start of flowering was later placed under net when the crop attained 10% flowering. The cages were stitched using 16-mesh size nylon net of 10 m x 10 m x 3.5 m size. In OP, the plants were exposed to natural open pollination and Bee-Q plots were similar to those of OP but were sprayed with Bee-Q. The yield parameters were recorded in different treatments and the data were statistically analyzed using factorial arrangement in randomized block design.

Results and discussion

Floral biology

The honeybees foraged fennel both for nectar and pollen whereas, the dipterans foraged for nectar only. The first flush of small yellowish flowers comprised mainly of completely protandrous hermaphrodite flowers with a few staminate ones too. The flowers started opening at 7.00 h and at about the same time anther dehiscence occurred and petals started withering in the afternoon. The stigma became receptive only after anther dehiscence and remained so for 2.3±0.4 days. The anther dehiscence from late maturing umbels may result in their mass shedding on receptive stigmas as reported by Kerner (1897) and Purseglove (1968). Highest pollen viability was recorded from freshly

opened anthers confirming the findings of Shilova (1972). Peak anthesis occurred during 11.00–14.00 h as reported by Baswana (1984).

Diversity of insect visitors

The floral visitors on fennel included 39 species belonging to 20 families and 7 orders (Table 1). Hymenopterans (47.1%) and dipterans (50.3%) were the two most prominent groups of flower visitors contributing 97.4% of the total visitors. The six Apoidea species recorded on fennel contributed 39.5% of the total visitors and the Italian honeybee *A. mellifera* was the most prominent, comprising 32.5% of the flower visitors followed by Indian hive bee *A. cerana* F. (4.3 %) and rock bee *A. dorsata* F. (2.6%). Among the other hymenopterous visitors (7.6%), unidentified Hymenoptera sp. 1 was the major one (3.8%).

Among the 17 dipteran species (comprising 50.3%), 8 species of the syrphid flies comprised 41.4% of the total visitors followed by 6 species of *Musca* (8.0%). The syrphid fly, *Episyrphus balteatus* De Geer was the major floral visitor (24.7%) after *A. mellifera* followed by *E. arvorum* L. (6.2%), *Eristalis* sp. 1 (5.6%) and *Musca* sp. 1 (4.4%). Other visitors contributed only 2.7% of the total visitors.

Earlier studies indicated that *A. florae* (Sagar 1981; Baswana 1984) and *A. mellifera* were the chief floral visitors of fennel (Youngken 1950, 1956; CCS HAU 2000, 2001; Chaudhary *et al*. 2002). The other prominent visitors were syrphid flies (*E. balteatus* and *Sphaerophoria scripti*) (Baswana 1984; Ricciardelli & Albore 1986; Ruppert & Klingauf 1988) and wild bees like *Andrena minitula* Kirby (Ricciardelli & Albore 1986) and *Osmia rufa* L. (Matuszak 1995). *A. mellifera* and many syrphid flies were reported as major visitors from Haryana (CCS HAU 2000, 2001).

Temporal abundance of floral visitors

For this study, data for 11 most abundant and important floral visitors was considered (Table 2). *A. mellifera* was most abundant over time and space with 15.7 bees m^{-2} observation $interval^{-1}$ followed by *E. balteatus* (11.9), *E. arvorum* (3.0), *Eristalis* sp. 1 (2.7), *Musca* sp. 1 (2.1) and unidentified *Hymenoptera* sp. 1 (1.8). *A. mellifera* started foraging at 09.05 h (6.3 bees m^{-2}) and peaked during 11.00–15.00 h (24.7–31.7), declined at 17.00 h (13.3) and was very low at 18.00 h (4.0). *A. dorsata* began foraging at 09.00 h (1.0 bees m^{-2}), peaked during 10.00–12.00 h (3.7–5.3) declined in the afternoon and was not recorded after 14.00 h. Like other two *Apis* species, *A. cerana* too began foraging at 09.00 h (0.3 bees m^{-2}), peaked during 11.00–12.00 h (4.7) declined later and was not recorded after 16.00 h. The wasp *Polistes herbaeus* F. started its activity late at 12.00 h and peaked at 13.00 h (0.7 wasps m^{-2}) and was not recorded from 16.00 h onwards. Unidentified Hymenoptera sp. 1 was present throughout the day in moderate numbers and peaked during 09.00–10.00 h (4.0–5.7 individuals m^{-2}).

E. balteatus was recorded on fennel throughout the day, was low at 06.00 h (0.3 flies m^{-2}) and peaked during 08.00–10.00 h (21.0–26.3) with another minor peak at 15.00 h (12.3) and 17.00–18.00 h (11.3–11.7), and remaining moderate at other periods of observation. *E. arvorum* had low population levels up to 07.00 h, peaking during 10.00–11.00 h (3.0–4.3 flies m^{-2}) with another peak at 15.00 h (6.3) and moderate populations later. *Eristalis* sp. 1 population peaked during 07.00–08.00 h (6.3–11.7 flies m^{-2}) and was low to moderate afterwards. *Musca* sp. was abundant in the morning, peaking during 07.00–09.00 h (3.7–4.3 flies m^{-2}) declining considerably afterwards, disappearing at noon and with another low population late in the afternoon from 15.00 h (2.3) to 18.00 h (7.0).

The intensity of foragers and their thresholds for foraging are influenced by the nature of crop bloom visited, possibly through the phenomenon of anthesis and/or rhythm of nectar and/or pollen presentation and weather factors. *Apis* species started foraging when temperature threshold reached at 09.00 h in the morning, whereas, all the dipterans and unidentified hymenoptera sp. 1 having solitary existence foraged throughout the day. All the *Apis* species started foraging late (09.00

Table 1. Abundance and diversity of insect visitors in nature (OP) and Bee-Q treated plots on fennel

Insect visitor	Family	Mean population day^{-1} m^{-2}		Proportion of total (%)		Increase over
		OP	Bee-Q	OP	Bee-Q	OP (%)
Hymenoptera						
Apoidea						
Apis mellifera L.	Apidae	203.7	319.3	32.5	39.7	56.8
A. dorsata F.	Apidae	16.0	28.7	2.6	3.6	79.4
A. cerana F.	Apidae	26.7	42.7	4.3	5.3	59.9
A. florae F.	Apidae	0.3	0.3	0.1	0.1	0.0
Ceratina sexmaculata Smith	Apidae	0.3	0.3	0.1	0.0	0.0
Trigona irridipennis L.	Meliponeae	0.3	0.3	0.1	0.0	0.0
Total Apoidea		247.3	319.3	39.5	40.0	29.1
Other Hymenoptera						
Unidentified Hymenoptera sp. 1		23.7	30.7	3.8	3.8	29.5
Camponotus sp.	Formicidae	8.0	3.7	1.3	0.5	-53.8
Unidentified Gen. & sp.	Formicidae	1.0	0.3	0.2	0.1	-70.0
Polistes hebraeus F.	Vespidae	1.7	0.3	0.3	0.1	-82.4
Vespa orientalis L.	Vespidae	0.3	0.0	0.1	0.0	-100.0
Unidentified Hymenoptera sp. 2		13.0	18.7	2.1	2.3	43.8
Total other Hymenoptera		47.7	53.7	7.6	6.7	12.6
Total Hymenoptera		289.0	448.3	47.1	55.7	52.0
Diptera						
Episyrphus balteatus De Geer	Syrphidae	155.0	142.0	24.7	17.6	-8.4
Episyrphus sp.	Syrphidae	13.0	27.3	2.1	3.4	110.0
Eristalis tenax L.	Syrphidae	6.3	3.7	1.0	0.5	-41.3
Eristalis arvorum L.	Syrphidae	*39.0*	*45.7*	*6.2*	*5.7*	*17.2*
Eristalis sp. 1	Syrphidae	35.3	37.0	5.6	4.6	4.8
Eristalis sp. 2	Syrphidae	1.0	0.0	0.2	0.0	-100.0
Eristalis sp. 3	Syrphidae	2.0	0.3	0.3	0.1	-85.0
Eristalis sp. 4	Syrphidae	8.0	7.0	1.3	0.8	-12.5
Musca sp. 1	Muscidae	27.3	31.7	4.4	3.9	16.1
Musca sp. 2	Muscidae	7.3	8.7	1.2	1.1	19.2
Musca sp. 3	Muscidae	2.0	1.0	0.5	0.1	-50.0
Musca sp. 4	Muscidae	8.0	7.0	1.3	0.9	-12.5
Chrysomyia bezziana Vill.	Muscidae	3.0	3.3	0.5	0.4	10.0
Unidentified Gen. & sp.	Muscidae	0.3	0.0	0.1	0.0	-100.0
Bombus sp.	Bombylidae	4.7	7.0	0.8	0.9	48.9
Unidentified Diptera sp. 1		1.0	0.3	0.2	0.1	-70.0
Unidentified Diptera sp. 2		1.7	0.3	0.3	0.1	-82.4
Total Diptera		312.7	324.3	50.3	40.3	3.0
Coleoptera						
Coccinella septumpunctata L.	Coccinellidae	13.3	34.0	1.9	4.2	188.1
Raphilopalpa foevicollis	Chrysomelidae	0.0	0.7	0.1	0.1	40.0
Heteroptera						
Leptocoris augar F.	Coreidae	1.7	0.3	0.3	0.1	-82.4
Lepidoptera						
Lampides boeticus L.	Lycaenidae	0.0	0.0	0.1	0.0	0.0
Pieris brassicae L.	Pieridae	0.3	0.0	0.1	0.0	66.7
Colias fieldi edusino Butler	Pieridae			0.1	0.0	0.0
Danais chrysippus L.	Danaidae	0.3	0.0	0.1	0.0	0.0
Zygoptera						
Unidentified		0.3	0.7	0.1	0.1	133.3
Spider		0.0	0.0	0.1	0.0	0.0
Unidentified		0.7	0.0	0.1	0.0	0.0
Total others		16.7	35.7	2.7	4.4	113.8
Grand total		624.7	805.0	-	-	28.5

OP=Open pollination

h) and *A. mellifera* was the most abundant and had a longer foraging period (up to 18.00 h), whereas, *A. cerana* foraged up to 16.00 h and *A. dorsata* only till 14.00 h. *A. dorsata* has been reported to be more active only till the afternoon on different cultivars of rapeseed and mustard (Chaudhary 2003). Surprisingly, *A. cerana* was not recorded after 16.00 h which may be due to pre-orientation of the colony to other more attractive flora in the near vicinity.

Peak bee activity was recorded for a longer duration from 10.00 h to 16.00 h and that of other pollinators from 07.00 h to 11.00 h with a minor peak in the late afternoon. However, Narayana *et al*. (1960) and Baswana (1984) reported a shorter peak activity of the bees from 11.00 h to 14.00 h. The highest amount of nectar and nectar sugar concentration was between 12.00–14.00 h (Atallah *et al*. 1989) and it coincided with peak honeybee activity, as the bees require high amount and concentration of sugars in the nectar. The peak activity of dipterans and other hymenopterans on the other hand was in the morning hours and late in the afternoon synchronizing with their requirement of high amount of nectar with low sugar concentration.

Effect of Bee-Q on abundance of floral visitors

Bee-Q had a significant positive effect on the abundance of Apoidea floral visitors as it increased their population by 29.1% over control. The increase in other hymenopterans was only 12.6% whereas, in the case of population of dipterans it was almost insignificant (only 3.0%) (Table 1).

Among the Apoidea, both the domesticated bee species (*A. mellifera* and *A. cerana*) registered an increase of 56.8% and 59.9%, respectively, in their population whereas in the rockbee *A. dorsata*, the increase was 79.4%. Surprisingly, *A. florea* along with *Ceratina sexmaculata* Smith and *Trigona irridipennis* L. did not show any such increase. Among the other hymenopterous visitors also, similar increasing trend was recorded in unidentified Hymenoptera sp. 1 and 2 (29.5% and 43.8%) whereas, in rest of the species a significant negative interaction was recorded.

Among the dipterans, *E. balteatus* population was lowered marginally (by 8.4%) with Bee-Q application but that of its close species, *Episyrphus* sp. more than doubled. The population of *E. tenax* L., *Eristalis* sp. 2, 3 and 4 decreased drastically, but that of other *Eristalis* sp. increased significantly. Population of bumble bee *Bombus* sp. also increased by 48.9% after Bee-Q application, whereas, that of rest of the dipterans decreased drastically. Among the other visitors, population of the beetles was higher and that of rest of the species decreased and remained static.

Effect of Bee-Q on temporal abundance of floral visitors

Bee-Q application increased the Apoidea population over time and space compared to untreated check (Table 2). *A. mellifera* started foraging early and continued up to 30 minutes later in the plots treated with Bee-Q than in the untreated plots. The proportion of population at 18.00 h and later was however, low to be of any significance. For all the three *Apis* species, the proportion of increased population was naturally more during the most active period of activity. In *A. cerana* only, the foraging period was lengthened by 1 hour from 16.00 h to 17.00 h, whereas, in *A. dorsata*, though the mean population increased significantly the total foraging period was shortened by 1 hour from 14.00 h to 13.00 h compared to the population in untreated control plots.

In the case of unidentified Hymenoptera sp. 1, though the population was more in Bee-Q treatment, no definite time trend was observed, whereas, in *P. hebraeus*, it caused a negative trend. Among the dipterans, Bee-Q application did not show apparent changes in spatial distribution patterns, their overall population remaining more or less constant.

Yield

The seed yield of fennel during 1998–99 was comparatively higher than during 1999–2000 (Table 3). The mean seed yield in WIP was merely 5.2 g plant^{-1} compared to 28.9 g in

Table 2. Influence of Bee-Q on the temporal abundance of insect pollinators on fennel

Insect visitor	Mean population of insect visitors m^{-2} during different hours													
	06.00	07.00	08.00	09.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	Mean
Open pollination (OP)														
Apis mellifera L.	0.0	0.0	0.0	6.3	23.3	27.0	28.7	27.7	31.7	24.7	17.0	13.3	4.0	15.7
A. dorsata F.	0.0	0.0	0.0	1.0	4.3	5.3	3.7	1.3	0.3	0.0	0.0	0.0	0.0	1.2
A. cerana F.	0.0	0.0	0.0	0.3	2.3	4.7	4.7	2.7	0.7	0.3	2.0	0.0	0.0	1.4
Unidentified Hymenoptera sp. 1	1.0	0.7	2.0	5.7	4.0	2.7	2.0	1.0	0.7	0.3	0.0	1.7	2.0	1.8
Polistes hebraeus F.	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	0.3	0.3	0.0	0.0	0.0	0.1
Episyrphus balteatus De Geer	0.3	12.3	21.0	26.3	22.7	10.7	6.3	6.0	6.3	12.3	7.7	11.3	11.7	11.9
Episyrphus sp.	0.0	4.7	6.0	1.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	1.0
Eristalis tenax L.	2.0	2.7	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.3	0.3	0.5
Eristalis arvorum L.	0.0	1.0	2.7	3.0	4.3	4.3	3.0	3.0	2.7	6.3	4.0	3.3	1.3	3.0
Eristalis sp. 1	0.7	11.7	6.3	3.7	1.7	1.7	1.7	1.3	0.3	0.7	1.7	1.7	2.3	2.7
Musca sp. 1	4.3	3.7	3.7	1.7	1.3	0.3	0.	0.7	0.7	0.7	1.0	2.3	7.0	2.1
Mean	0.8	3.2	3.6	4.8	6.4	5.7	5.0	4.4	4.4	4.6	3.3	3.4	2.9	
SD	0.4	1.5	2.0	2.5	2.8	2.5	2.7	2.6	3.1	2.6	1.7	1.5	1.2	
Bee-Q														
Apis mellifera L.	0.0	0.0	0.0	9.3	33.7	40.0	41.0	40.0	46.7	44.7	36.7	18.0	2.0	24.0
A. dorsata F.	0.0	0.0	0.0	2.0	11.0	9.7	5.7	0.3	0.0	0.0	0.0	0.0	0.0	2.2
A. cerana F.	0.0	0.0	0.0	2.0	10.0	13.0	9.7	5.0	2.3	0.7	0.0	0.3	0.0	3.3
Unidentified Hymenoptera sp. 1	2.0	0.3	2.7	11.7	2.3	1.0	2.3	1.7	1.0	0.7	1.3	2.3	1.3	2.4
Polistes hebraeus F.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Episyrphus balteatus De Geer	0.0	10.3	15.3	21.7	18.0	9.3	6.7	5.0	6.3	6.3	8.0	21.0	14.0	10.9
Episyrphus sp.	0.0	4.0	3.0	1.7	2.0	1.3	1.7	1.3	0.0	2.7	2.0	4.3	3.3	2.1
Eristalis tenax L.	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Eristalis arvorum L.	0.0	1.3	2.0	3.3	5.0	3.7	6.0	4.7	5.3	1.7	3.3	6.3	3.0	3.5
Eristalis sp. 1	1.0	10.3	4.0	4.7	2.3	1.0	1.3	0.7	0.0	0.3	1.0	6.0	4.3	2.8
Musca sp. 1	5.0	6.0	5.7	3.3	1.7	0.0	0.3	0.0	0.3	0.0	1.0	2.7	5.7	2.4
Mean	1.2	2.8	3.0	5.8	8.4	7.8	7.3	5.8	6.2	5.4	5.1	5.7	3.0	
SD	1.8	4.4	4.8	6.8	10.6	3.9	12.3	12.2	14.4	13.9	11.4	7.7	4.3	

Table 3. Effect of different modes of pollination on yield of fennel

Treatment	Seed weight (g plant^{-1})			% increase over		
	1998–99	1999–2000	Mean	WIP	OP	BP
WIP	6.6	3.7	5.2	-	-	-
OP	35.0	22.8	28.9	474.7	-	11.90
BP	34.6	18.6	26.6	413.5	-10.6	-
Bee-Q	39.7	28.9	34.3	553.4	13.7	27.2
CD (P=0.05)	3.8	2.7	4.2			

Values are means of 3 replications, 10 plants per replication
WIP=Without insect pollination; OP=Open pollination; BP=Bee pollination

open pollinated plots (an increase of 474.7% over WIP) and 26.6 g plant^{-1} in BP plots (an increase of 413.5% over WIP), the latter two being at par with each other. Highest yield of 34.3 g plant^{-1} (an increase of 553.4% over WIP) was recorded in plots treated with Bee-Q.

The study clearly revealed the contribution of insect pollination in fennel, being 5.5 times increase over WIP. The yields in BP were at par with OP signifying the role of insect pollinators other than honeybees, especially the dipterans like syrphid flies - *E. balteatus, E. arvorum¸ Eristalis* sp. 1 and *Musca* sp. 1. The lowest yields in WIP (5.2 g plant^{-1}) in this study compared to OP (29.7 g), BP (26.6 g) and Bee-Q (33.8 g) are reflective of the optimum, rather saturated insect pollination.

Since syrphids, other dipterans and wild bees are unmanageable and mostly unavailable, it is recommended to keep honeybee colonies in or around the fennel fields for obtaining higher yields.

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