

Exploratory studies on occurrence and potential benefits of high fruit yielding reproductive phenophasic variants of *Pithecellobium dulce* in augmenting fruit based semi-arid agro forestry systems

ABSTRACT

Background: *Pithecellobium dulce* is a multipurpose legume tree species of high ecological significance. Several reports indicate existence of huge genetic diversity within the natural population of the species. Various morphological parameters have been used to assess intra species genetic diversity, however, there is no report available so far on diversities in reproductive phenology of *P. dulce* of semi-arid or arid climate.

Methods: The present paper is based on assessment of diversity in flowering phenophases through construction of phenological calendar incorporating temporally observable morpho-phenotypic descriptors for reproductive behaviour of individual trees comprising natural population of the species at designated study sites during a period of three years. The study was carried out during September, 2015 and March, 2019 at Ajmer, Rajasthan, India. Data were periodically obtained and statistically analysed.

Results: Majority of trees of flowering stage (89.94%) exhibited normal or winter blooms in which flowering was initiated in almost synchronised manner during December; 10.05% of normal blooming trees inconsistently showed additional early or autumn blooms during either September or October or November; 2.58% of trees exhibited early blooms in which flowering was consistently initiated in the month of September in addition to normal blooms. The overall production and availability of fresh fruits in early-cum-normal episodic blooming trees were greater as compared to only normal blooming trees. Though, the numerical fruit productivity in winter blooms was superior to autumn, the pomometric characteristics were inferior in former in early-cum-normal episodic blooming trees.

Conclusion: The present work explores agronomically valuable variants of *P. dulce* and also reports causes of appearance of persistent fruits and sporadic *in-situ* germination of seeds. Based on above findings, the paper also makes evolutionary predictions that how a shift in flowering phenology of *P. dulce* as exhibited by the elite variants could have long-term implications for reshaping of future landscapes of semi-arid or arid climate. Conclusively, Winter to autumn phenophasic shift in flowering in *P. dulce* is economically productive, evolutionarily progressive, and environmentally well cued partial retrieval. Moreover, the phenophasic variants could serve as candidate plus trees that deserve out of the season floral management and clonal propagation, thereby the species may get a fillip to status up gradation from minor fruits to major fruit category.

40 **Keywords:** Phenology; *Pithecellobium dulce*; genetic diversity; fruit persistence; semi-arid

41

42 1. INTRODUCTION

43 *Pithecellobium dulce* (Roxb.) Benth. belongs to the sub-family Mimosoideae of family
44 Fabaceae. The species is native to the tropical America (Mexico, USA, Argentina, Bolivia, Brazil,
45 Colombia, Ecuador, French Guiana, Guyana, Paraguay, Peru, Surinam, Uruguay and Venezuela), but
46 has now become naturalized in India, China, Cambodia, Malaysia, Myanmar, Philippines, Puerto
47 Rico, Sudan, Tanzania, Thailand, Vietnam and cultivated there as economic and ornamental trees [1,
48 2]. In India, *P. dulce* is present throughout the country except Jammu and Kashmir, Himachal
49 Pradesh, Sikkim, Arunachal Pradesh, Assam, Nagaland, Meghalaya, Manipur, Tripura and Mizoram
50 [3]. The species have wide ecological amplitude with respect to soil types and annual rainfall, in India
51 it grows well in semi-arid regions characterized by mean monthly temperatures ranging from 7 to 8°C
52 in January to 40 to 42°C in May and June. It is generally considered heat and drought resistant tree
53 world over [4]. *P. dulce* is a medium-sized fast growing tree commonly attaining a height up to 10-15
54 metres. Branching pattern is irregular and leaves are bi-pinnate with thin spines in pairs at the base of
55 leaves that range from 2 to 15 mm in length. The growth of new leaves coincides with the loss of old
56 leaves which give the tree an evergreen appearance. Inflorescences are panicles that differentiate
57 axillarily or terminally from the leafy branches of the tree. Flowers are borne on short panicles 10 to
58 20 cm in length, often as terminal compound inflorescences. Each panicle is composed of 20 to 30
59 floral units potentially capable of fertilization. Individual flowers are greenish-white, sessile present in
60 small stalked heads consisting of 10-15 floral buds; calyx and corolla small, single thread like tubular
61 pistil longer than stamens, pink in colour with capitate stigma; and stamens are fifty in numbers that
62 give hairy appearance. Because of nitrogen fixing ability and high ecological values, *P. dulce* trees
63 are often planted on waste land for reclamation, shelter belt plants and roadside ornamentals [5,6].
64 They are extensively planted for production of protein rich live stock fodder and fuel wood in Asia,
65 Latin America and Africa [7,8,9]. *P. dulce* has been designated as minor fruit trees and considered
66 one of the most suitable trees for alley cropping. Fruits are plump, constricted between the seeds,
67 spirally coiled and spongy white arils surround 5 to 12 shiny black seeds within the pod. Arils are
68 sweet and acidic in taste so consumed by birds which also disperse seeds in the process of eating
69 [10]. The seed contains 20% oil which is used in soap industries, refined seed oil is edible. Flowers
70 attract honey bees and significantly contribute to honey making. Trees have great potential for rearing
71 lac insects. In addition to ecological significance of trees and economic values of fruits, *P. dulce* has
72 been reported to possess many pharmacological properties and clinical applications that include *inter*
73 *alia* Pitheduloside extracted from the plant are anti-inflammatory, anti-microbial, anti-tubercular,
74 spermicidal, protease inhibitor, anti venom and abortifacient [11,12]. In folklore, *P. dulce* is being used
75 to cure leprosy, venereal diseases, peptic ulcers, sores, toothache, convulsions, dyspepsia and
76 dysentery [13]. Leaf extract has been used to relieve pain, convulsions, indigestion and diabetes. Arils
77 are being used in preparation of beverages. Extracts of fruits, seeds, leaves, and bark have been
78 demonstrated to possess antioxidant properties potentially capable of curing ulcers, cancers and

79 gastrointestinal ailments [14,15,16,17,18]. In view of vast utilities of *P. dulce*, it is pertinent to explore,
80 identify, and select the variations with superior agronomic traits from the population. Reports are
81 available on genetic diversity in *Pithecellobium elegans* [19], as well as selections of agronomically
82 desirable genotypic variants of *P. dulce* from natural population with large pods containing small
83 seeds and sweet less astringent arils, and variegated plants with green and white leaves. They are
84 being clonally propagated and grown in gardens in Thailand, Philippines, and Hawaii [20,21]. Quite
85 recently, Goyal et al., 2014 [22], have made assessment of genetic diversity in *P. dulce* germplasm of
86 Rajasthan state using RAPD and ISSR markers. Their findings indicate a high level of morphological
87 and genetic diversity in *P. dulce*. Their selections were based on the phenotypic assessment of
88 various characters viz., branching habit, branching pattern, canopy size, number of primary branches,
89 colour of bark, height of tree, leaf shape, number of flowers per inflorescence, pod size, number of
90 seeds per fruit, leaf size and percent seed germination. There has been no report so far on the
91 diversity in flowering and fruiting phenology of the species. Therefore, the present paper attempts to
92 identify agronomically advantageous variations in flowering-fruiting phenophases of *P. dulce* growing
93 in semi-arid climate of Ajmer (RIE campus, Nag Pahar hillocks and along Ajmer-Pushkar road side)
94 with prime objective to enhance production and prolong the availability of fruits respectively.
95 Ecological phenomena of persistence of fruits throughout the year and sporadic *in situ* germination of
96 seeds under specific environmental conditions have also been studied. Undoubtedly, such exploration
97 and selections would help plant breeders to design appropriate strategies for multiplication and
98 conservation of the elite variants or germplasm and also pave the way for further genetic
99 improvement of cultivars. Additionally, these phenophasic variants could serve as potential candidate
100 plus trees for out of the season floral management through biotechnical interventions. If successfully
101 employed the species may get a fillip to status up gradation from minor fruits to major fruit category.
102 Nevertheless, the greater understanding of diversity in reproductive strategies of *P. dulce* in
103 conjunction with time and environmental dynamics would provide better insights into predictive
104 evolutionary processes that might impact on future reshaping of semi-arid or arid landscapes.

105

106 **2. MATERIALS AND METHODS**

107 Three study sites of naturally growing populations of *P. dulce* were identified within 10-15
108 kilometres range at Ajmer, Rajasthan, India. Study sites: RIE campus, Nag Pahar hillocks and Ajmer-
109 Pushkar road side barren land were marked as site – I, II and III respectively. Phytosociological
110 survey was initially conducted at all study sites to identify and enlist species of tree communities,
111 species of *Pithecellobium* and numbers of individuals of *P. dulce* during August-September, 2015 at
112 all study sites. Periodical observations were made during August 2015 and December 2018 to collect
113 data on phenology of *P. dulce* with particular focus on flowering and fruiting events to explore diversity
114 in phenophases with respect to onset and completion of flower initiation, flowering continuum, fruit
115 initiation, fruit maturation and fruit ripening. Annual records of number of trees with persistent fruits
116 and number of persistent fruits per trees were also maintained for all study sites during the period
117 under study. Phenological observations on flowering frequencies of all tree species constituting the

118 plant community of the habitat under study were also made to classify four levels of species: continual
119 species, episodic or sub-annual species, annual species, and supra-annual species.

120 Data pertaining to comparative account of two blooms, viz., early or autumn and normal or
121 winter with respect to number of branches bearing flowers, position of inflorescence on trees, number
122 of inflorescences per branch, number of floral units per inflorescence, number of fruits per
123 inflorescence, number of seeds per pod, average length and diameter of fruits, and degree of
124 synchrony in flowering of elite variants were separately maintained and statistically analysed and
125 presented in tabular forms. Data recording on flowers necessitates elaboration on structure of
126 inflorescences to conceptualize experimental use of floral units equivalent to flowers potentially
127 capable of fertilization. Inflorescences are panicles that differentiate axillarily or terminally from the
128 leafy branches. Each panicle produces small clusters of 2 to 5 heads all along its length of 10-20 cm,
129 at the distance of 1.0 cm in spiral manner. Clustered heads originate from a single point
130 asynchronously. Each head consists of about 10 to 20 small floral buds connected to the point of
131 origin through a stalk. All buds of a head open synchronically, therefore, anthesis is of long duration
132 when about fifty of hair like stamens in a flower grows further along with long thread like single pink
133 coloured pistil. So, clustered flowers give hairy appearance with fragrance and extra floral nectaries
134 attract honey bees and other insect pollinators. If all floral buds of all clustered heads of each
135 inflorescence are counted before anthesis, about 3000-4000 flowers should have been produced in
136 each inflorescence. However, fruit setting in each inflorescence never exceeded 10-15 in our
137 observations thereby making the fruit to flower ratio as low as 0.003. Hence, the huge numbers of
138 flowers per inflorescence posed a big challenge in experimental data recording for numbers of flowers
139 per inflorescence. To overcome such obstacle, we examined many samples of inflorescences from
140 different blooms as well as trees and found that majority of floral buds constituting an inflorescence
141 are not functional in reproduction because of absence of pistils in flowers, improper orientation of
142 stigmas, partially drying up of long tubular pistils, non-opening and drying up of many floral buds. Data
143 on numbers of functional flowers capable of fertilization was obtained after long observation on
144 numbers of floral heads showing anthesis per day or a week, duration of anthesis and blossoming till
145 fruit setting. Therefore, floral units in observation table correspond to numbers of functional flowers
146 capable of reproduction per inflorescence. Data were also utilised in construction of flowering-fruiting
147 phenophasic calendar of *P. dulce* for specified population during the study period. Vaucher
148 specimens and seeds of agronomically advantageous flowering-fruiting phenophasic variants or
149 genotypes were deposited in herbaria of Botany Department of RIE, Ajmer.

150

151 **3. RESULTS AND DISCUSSION**

152 **3.1 Diversities in flowering-fruiting phenophases in natural population of *P. dulce***

153 Species of tropical plant communities vary considerably with respect to flowering onset
154 timings viz., winter, spring, summer or autumn; frequency of flowering, several times in a year, or
155 once in several years; and duration of flowering from a few days to the whole year. Thus the onset
156 timing, duration, and frequency of flowering define reproductive phenological patterns of species

157 which interact with each other in order to display spectacular diversities in flowering patterns what we
158 observe in nature [23,24,25,26]. Furthermore, phenological patterns in tropical trees particularly
159 flowering and fruiting are determined through interactions between short-term environmental events
160 and evolutionary forces. Alternatively, flowering phenology is both under genetic control and is plastic
161 to environment, that means changes in climatic conditions may trigger the expression of phenotypic
162 responses currently hidden [27]. Different geographic locations comprise their own edaphic and
163 climatic conditions such as soil nutrients (level of N in soil), variation in rainfall, changes in
164 atmospheric temperature, photoperiod, irradiance and sporadic environmental events that serve to
165 provide environmental cues in triggering floral phenological events in tropical plants
166 [28,29,30,31,32,33,34,35,36,37,38,39,40]. Newstrom et al., 1994 [41], and Engel et al., 2005 [42],
167 have described four levels of flowering frequency: continual species that continuously flower
168 throughout the year, episodic species that flower more than once a year, annual species that flower
169 once a year, and supra-annual species that flower less frequently than once a year. Based on above
170 classification, *Cordia crenata*, *Commiphora wightii*, *Manilkara zapota*, and some varieties of *Morus*
171 *alba* constitute the continual species; about 60% of the population of *Prosopis cineraria*, *Acacia*
172 *nilotica*, and few individuals of *Pithecellobium dulce*, *Psidium guajava*, *Cordia dichotoma*, *Azadirichta*
173 *indica*, *Grewia asiatica* constitute sub-annual or episodic species; while some cultivars of *Mangifera*
174 *indica*, *Bamboos*, and *Agave americana* constitute supra-annual species; whereas remaining majority
175 of plants constitute annual species as observed in the habitat under study. Similar observations on
176 frequency of flowering in above mentioned species growing in different habitats have also been
177 reported by [43,44,45,46,47,48]. *P. dulce* generally flowers and fruits between December to May and
178 February to August respectively in its native habitat [2]. In Indian tropical deciduous forests, *P. dulce*
179 flowering occurs in January and February and fruiting in April and June respectively [49]. However, a
180 bit altered flowering and fruiting phenologies have been observed in Philippines and West Java where
181 they flower in October-November and April-June respectively. While fruiting at these two locations
182 occurs in January-February and July to August respectively [1]. In Puerto Rico fruiting has been
183 observed throughout the year [2]. Therefore, *P. dulce* exhibits three levels of reproductive
184 phenological patterns based on annual flowering frequency as annual flowering at most of the
185 geographic locations world over, continual flowering in Puerto Rico and episodic flowering by some
186 individuals at semi-arid habitat under study. In present study at Ajmer, India, intra species flowering-
187 fruiting phenology at three designated study sites – I, II, III have been consistently observed during
188 September, 2015 and December, 2018 for flower initiation, fruit initiation, maturation and ripening of
189 fruits. About 90% of flowering individuals of natural population exhibited almost synchronous
190 behaviour for onset of flowering during winter whereas, approximately 10% of them showed
191 alterations. Out of 10% alterations, 7.47% alterations were not consistent with respect to floral
192 initiation timings, 2.58% alterations were consistently observed throughout the study duration (Table 1
193 & 2).

194 In other words, these individuals exhibited offseason flowering, i.e.; two blooms, viz., autumn
195 and winter occur consecutively in same tree thereby the flowering and fruiting durations are prolonged
196 (Fig. 1- A & B). They belong to the episodic or sub-annual species level based on flowering

197 frequency as described by Newstrom et al., 1994 [41]. Similar phenophasic change in flowering of
198 *Prosopis cineraria* or Khejari has been reported by Krishnan et al., 2015, in Indian Thar desert [47].
199 On account of prolonged flowering and fruiting in *P. dulce*, the overall quantitative and qualitative
200 productivity and time duration of availability of fruits are greater in early-cum-twice blooming trees as
201 compared to normal and single blooming trees (Fig. 3&4). However, early formed fruits during
202 December and January are highly vulnerable to frugivores since very few other trees with fruits are
203 available in vicinity as observed in the habitat under study. Table-3 provides comparative account of
204 flowering and fruiting in autumn and winter blooms of early and twice flowering individuals of *P. dulce*.
205 It is evident that winter or normal bloom is superior to autumn or early bloom with respect to numbers
206 of inflorescences, flowers and fruits, also winter bloom is more synchronous as compared to autumn
207 blooms in flower initiation timing, blossoming period and fruit-setting, notwithstanding that fruits
208 produced through autumn blooms are more robust with respect to length, diameter, and number of
209 seeds (Fig. 1-D & Fig. 4). Rodriguez et al., 2016 [50] has reported similar observations that during
210 flowering off-peak, episodic variants flowering for shorter periods with even less synchronicity
211 proportionally set more fruits since they were less affected by fluctuations in biotic and abiotic factors.
212 During the three years study period, about 17% of trees of the population of *P. dulce* remained in non-
213 flowering state. They were not the same trees rather different trees did not flower either first or second
214 or third year. However, about 34% of all non flowering trees showed late flowering with onset timings
215 either in February or March. We consistently observed flowering abnormalities in most of these trees
216 since they produced a very low number and much smaller size of inflorescences. Their flowering
217 durations and fruit setting were also very low probably because of non availability of resources such
218 as water, high level of air pollution or very old age of trees. Data have not been included in this paper
219 since they serve separate topic of research. In view of the natural episodic flowering in *P. dulce*, the
220 species is a potential candidate tree that deserve out-of-season management of flowering to avoid
221 detrimental harsh weather conditions of April, May, and June that hamper fruit development of normal
222 or winter blooms through biotechnical engineering in flowering phenology. Phenological engineering
223 of reproductive behaviour of fruit trees through biotechnological interventions involving exogenous
224 applications of plant growth regulators and adoption of appropriate agronomic practices such as
225 pruning, trimming, and chopping of branches have been successfully employed to induce off-season
226 flowering for enhanced fruit yield in mango [51], lychee [52], longan [53], custard apple [54], apple &
227 sweet cherry [55], and guava [46,56,57]. It would not only increase the fruit yield rather prolong
228 availability of fruits to take advantage of market opportunities. Genetic improvement of tree species
229 through conventional selection methods of plant breeding is highly laborious and time consuming. As
230 suggested by Narayan, biotechnological *in vitro* cultures and propagation techniques can circumvent
231 the bottlenecks through by passing the unwanted juvenile phase of tree species as performance
232 trouble-shooter. Therefore, phenologically plus trees such as *P. dulce* need to be put under prioritised
233 objectives of *in vitro* propagation technology in addition to endemic, threatened, endangered, and elite
234 germplasm not only to multiply and genetically modify them but also to maintain *in vitro* biodiversity
235 [58,59,60].
236

237 **3.2 Flowering-phenophasic shift to autumn could be an evolutionary event towards**
238 **better establishment of *P. dulce* under semi arid or arid climate**

239 In spite of quantitative inferiority of autumn blooms of *P. dulce* with respect to morphological
240 descriptors of reproductive behaviour (extent of flowering and fruiting) as compared to winter blooms,
241 pomometric characteristics of autumn bloom fruits were observed to be impressive as depicted
242 through graphical representations in fig. 4. Robust growth of autumn bloom fruits could be attributed
243 to abiotic and biotic components of the prevailing environmental complex. Favourable abiotic
244 environmental conditions of winter with respect to mild temperature, bright sun light, low or mild wind
245 velocity, adequate moisture level in soil and plant body, and low rate of evapo-transpiration in
246 conjunction with biotic factors such as availability of highly specialised pollinators- bees, sun birds and
247 bulbuls that concentrate on *P. dulce* since very few flowering trees were present in vicinity; provided
248 congenial conditions for fruit setting and development. However, concentration of frugivores was also
249 observed which proved to be highly detrimental to developing fruits that warranted special protection
250 to them. Moreover, brief winter shower coupled with greater monthly mean temperature during winter
251 months were growth promoting for fruits of autumn blooms whereas, same conditions were growth
252 retarding for flowering in winter blooms as noticed during 2016-17. In view of above observations in
253 the light of research findings by [24,61,62] that species that flower several times a year or episodically
254 as exhibited by some variants in present study should be more abundant than either annually or
255 supra-annually flowering species. They postulated that multiple clutches may have been selected to
256 reduce reproductive failure from fluctuating populations of pollinators. Therefore, the following
257 evolutionary predictions of future reproductive success of episodically flowering variants of *P. dulce*
258 may prove true in course of time for the habitat of semi-arid climate currently dominated by Acacia
259 species. A shift in flowering phenophase from winter to autumn may perhaps be the first evolutionary
260 step of the species towards better perpetuation and establishment to the semi arid or arid climate
261 characterized by low rainfall, high temperature, dryness of air, intense sun light and high velocity wind
262 for most of the period in a year. According to Elberling et al., 2001 [63], and Anderson and Hill, 2002
263 [64] findings that in out crossing insect pollinated plants, flowering during harsh seasons (winter or
264 early spring-December, January and February) may decrease reproduction compared with flowering
265 during favourable periods. In consonance with their findings we noticed a long lag phase in
266 reproductive processes after induction of flowering during December in winter blooms till mid
267 February when pollination and fruit setting started because of increase in number of pollinators,
268 whereas, pollination and fruit setting immediately begins with floral induction in case of autumn
269 blooms of *P. dulce* (Table 2). Currently, fruit maturation and ripening period of winter or normal
270 bloom, viz., April-June period is extremely harsh, hence detrimental to aril and fruit development.
271 Despite good tastes, nutritious and high medicinal values of fruits, *P. dulce* has not gone up beyond
272 the level of minor or underutilized fruits in many countries including India, however, the price of its
273 fruits in Indian market is costlier than imported American apples, and cherries which range between
274 Rs. 300 to 400 per Kg. They are also in high demand, however, the supply is abruptly constrained
275 due to low production. Harsh climatic conditions of summer in semi-arid or arid regions adversely

276 affect fruit development in wild habitats. Many fruits because of poor development of aril in the
277 absence of adequate moisture level in plant body and high atmospheric temperature get dry up and
278 become hard, in some cases that persist throughout the year attached with the parent trees (Fig. 1- E,
279 F). Similar findings have been reported by Mohandass et al., 2018, for woody tree species of tropical
280 seasonal forest in China [65]. Low atmospheric humidity triggers splitting of pods and subsequent
281 shrinkage (Fig. 1-C). Dryness induced leaf fall in May and June render top fruiting branches leafless
282 thereby exposing the fruits to frugivores that indiscriminately chop off developing or immature fruits. It
283 would also aid to spirally coiled hanging fruits pose resistance to the high velocity wind during
284 extreme summer and get easily detached from the trees (Fig. 2-B). Consequently, overall fruit yield is
285 drastically reduced and fruit to flower ratio is very poor. Gradual shift of reproductive events of winter
286 bloom towards autumn bloom through internal genetic mechanisms in response to evolutionary forces
287 to be perceptive to new environmental cues of adequate moisture level in plant body, decreasing day
288 length, and mild temperature regime as happens during autumn (September-October) to trigger
289 flowering phenophase. In course of time, if natural population of *P. dulce* acquire such characteristics
290 and flowering and fruiting phenophases completely shift from winter blooms to autumn blooms, all
291 reproductive events of the species including fruit dehiscence and seed dispersal ought to be
292 completed by the end of March, thereby a complete avoidance of harsh weather conditions of April,
293 May and June months of semi-arid and arid climate may occur. Under new phenophase, January,
294 February and March months would be a period of fruit development, maturation and ripening.
295 Congenial climatic conditions of spring would provide favourable conditions for proper fruit
296 development in *P. dulce*. Undoubtedly, the overall productivity in terms of quantity and quality of fruits
297 would be enhanced. *P. dulce* would be able to compete with other species in attracting varieties of
298 frugivores thereby wide seed dispersal would ensure enhanced multiplication and better
299 establishment of the species in semi-arid or arid climate. Encinas-Viso, 2014 [66]; Lavabre et al.,
300 2016 [67], and Garcia, 2018 [68] have also emphasised on importance of frugivore diversity in
301 reproductive success of tree species. The phenological shift in flowering is outcomes of interactions
302 between pollinators and other biotic and abiotic factors that led to evolution of long duration flowering
303 in *P. dulce*, which is exclusively pollinated by insects, therefore, in agreement with Elzinga, 2007 [69],
304 and Munguia-Rosas, 2011 [70], it would be appropriate to state that insect pollinated plants flower for
305 longer durations as compared to abiotically pollinated plants (Fig. 2-A).

306

307 **3.3 Persistence of fruits and sporadic in situ germination of seeds under specific** 308 **environmental conditions**

309 Flowering trees naturally shed their fruits when they are fully developed and ripened. Fruit
310 ripening in many tropical trees is completed within few months, however, some trees such as *Cassia*
311 *fistula*, *Thespecia populnea* shed their fruits after one or two years of fruit inception since their fruit
312 development and ripening processes are highly prolonged. Fruits remain attached with the parent
313 plant for more than one year and two generation fruits with distinct developmental stages could be
314 viewed at any point of time unless older generation fruits are mechanically detached from the trees.

315 Fruit persistence in *P. dulce* primarily seems sheer mechanical and environmental phenomena,
316 however, the influence of biotic factors cannot be ruled out. Least number of trees about 16.20% of
317 site-I (Man managed ecosystem) showed persistent fruits during the period of study, whereas, a
318 greater percentage of trees (51.32 and 58.82) of sites-II and III exhibited persistent fruits. These two
319 sites were apparently deficient in soil moisture content during the period of fruit development,
320 however, number of persistent fruits per tree were maximum at site- I (RIE campus), and site- II (Nag
321 Pahar hillocks) on account of dense tree top canopies and structural barriers to high velocity wind
322 through buildings and hill stones at site-I and II respectively. Sites-I&II showed the maximum number
323 of persistent fruits per tree since trees were sparsely scattered and directly subjected to intense sun
324 light and many of them were heavily infested with horned tree hoppers (Table-1). Studies on mode of
325 persistence of fruits in *P. dulce* reveal that those fruits whose developmental pace is slow due to low
326 level of moisture content and spirally coiled fruits get entangled with the spines or small branches that
327 remain under the cover of dense leaves (Fig. 1-E&F). Drying up of such fruits is slow and fruit stalk is
328 protected from frugivores while some parts of pods are eaten away, such fruits remain attached with
329 the parent trees for one or two years (Fig. 1-F&G). These persistent fruits slowly split into two halves
330 exposing their seeds which in most of the cases serve as microhabitat for breeding of insects such as
331 horned plant hoppers, butter flies and plant spiders which serve as pollinators for *P. dulce* as well as
332 neighbouring plants. Some of the persistent fruits sporadically showed *in situ* germination of seeds
333 under high humid conditions during rainy season, July and August (Fig. 2-C). About 7-10% of
334 persistent fruits were observed to exhibit *in-situ* germination of seeds in trees at sites-I and II probably
335 due to high humidity and shade conditions maintained through underneath decaying thick leaf debris
336 and stagnant wind around persistent fruits on account of structural barriers posed by buildings and
337 hillocks respectively; no *in situ* germination of seeds was observed at site-III where trees are exposed
338 in open space along the road side (Table 1). *In situ* germination of seeds in *P. dulce* is unique in the
339 sense they do not involve hormonal elicitation secreted through maternal fruit tissues since extremely
340 low numbers of persistent fruits under sporadic conditions exhibit such germination behaviour.
341 Therefore, it cannot be equated with either vivipary or crypto-vivipary. *In situ* germination behaviour
342 has been seen in those persistent fruits of *P. dulce* that get entangled with small branches and
343 possess some viable seeds. During hot and windy summer small cracks develop on the walls of the
344 pods which help in deposition of fine dust particles over the dried arils as well as empty spaces within
345 the cavities of fruits. Rain water easily percolates into the fruit cavities through the cracks during July
346 and August. Hygroscopic arils along with fine dust particles form thin substrata within the cavities of
347 pods which retain water for a week thereby helping seeds to absorb water and quickly germinate
348 within the pods since *P. dulce* shows orthodox seed storage behaviour and have wide range of
349 tolerance in germination with respect to temperature and light conditions, even very thin substratum
350 can support germination when seeds are oriented with sideward facing hilum as reported by Vargas-
351 Figueroa et al. 2015 [71]; and Guimaraes et al. 2016 [72]; on the basis of their seed germination
352 studies. However, some of the germinating seeds have been observed to be dropped on to the soil
353 and further grow. Moreover, many seedlings derived from those seeds are abnormally coiled being
354 confined within the walls of fruits (Fig. 2-C). Persistence of fruits is wide spread phenomena in *P.*

355 *dulce* particularly in semi-arid or arid climate, which commence in response to interactions between
 356 abiotic and biotic factors. When drastic changes in atmospheric temperature and humidity are
 357 perceived, horned tree hoppers, *Leptocentrus taurus* migrate from exposed branches of deciduous
 358 trees to the evergreen branches of *P. dulce* to get reprieve and shelter. They have been frequently
 359 observed sucking fruit sap, thereby rendering them highly vulnerable which gradually dry up under
 360 high temperature of summer. Being dehydrated, fruits no longer attract frugivores, thus they remain
 361 attached with the parent trees for several months in the bunch of dried partially eaten fruits by
 362 frugivores particularly parrots and bulbuls. Similar observations have also been reported by Tang et
 363 al. 2005 [73]. Hence, it cannot be regarded as a phenological event of reproductive process, however,
 364 it could serve as bio-indicator of high temperature and low humidity. Conversely, low temperature of
 365 winter is an essential prerequisite for floral induction in *P. dulce*, thus most of the trees of population
 366 respond to the low temperature (5-8°C) during December and exhibit floral induction in a
 367 synchronised manner. Therefore, data records on flowering phenology and persistence of fruits for a
 368 long period could accurately portray plant responses to climate change. Similar views have been
 369 expressed by Tooke and Battey 2010 [74], Siegmund et al. 2016 [75], and Wadgyamar et al. 2018 [76]
 370 in their research findings. It would not be surprising to know that how some Japanese climatologists
 371 have reconstructed climatic calendar of changes in spring time temperature in Kyoto, Japan for a
 372 period of 732 years since 9th Century on the basis of historical flowering phenological data series of
 373 Cherry tree, *Prunus jamasakura* [77].

374
 375 Table 1. Distribution, number of trees with persistent fruits and average number of *in-situ*
 376 germination in persistent fruits of *P. dulce* at three study sites during September 2015 –
 377 December 2018.

Study sites	Duration	No. of tree species	No. of species of <i>P. dulce</i>	No. of individuals of <i>P. dulce</i>	No. of trees with persistent fruits	No. of persistent fruits/tree Mean ± SE	% of persistent fruits showing <i>in-situ</i> germination
Site-I	2015-16	76	1	105	18	3.33 ± 0.442	8.34
	2016-17	75	1	95	14	4.5 ± 0.626	9.52
	2017-18	75	1	90	15	6.26 ± 0.407	9.58
Site-II	2015-16	26	1	31	15	4.26 ± 0.589	9.38
	2016-17	24	1	25	12	4.16 ± 0.548	10.01
	2017-18	21	1	20	12	4.5 ± 0.657	7.4
Site-III	2015-16	21	1	19	11	1.63 ± 0.278	-
	2016-17	20	1	17	10	1.6 ± 0.266	-
	2017-18	17	1	15	9	1.66 ± 0.235	-

379

Table 2. Phenological calendar depicting month-wise flowering-fruitlet phenophases of individual trees of *P.dulce* natural population during September 2015 – December 2018 at three study sites.

Study sites	Duration	Flowering-fruitlet phenophases of individuals	J	F	M	A	M	J	J	A	S	O	N	D
Site-I	2015-16	EFIs	Fr.m-3+2, Fc.-1, Fc-6	Fr.m-3+2, Fr.i.-1, Fc-6	Fr.r-1+2, Fr.m-1, Fr.i-6	Fr.r-1, Fr.m-6	Fr.r-6	Fr.r-6			Fi-3	Fc-3, Fi-2	Fr.i.-3, Fc.-2, Fi.-1	Fr.m-3, Fr.i.-2, Fc.-1, Fi.-6
		NFIs	Fc-86	Fc-85	Fr.i-82	Fr.m-78	Fr.r-75	Fr.r-70	Fr.r-10	Fr.r-5				Fi-90
	2016-17	EFIs	Fr.m-3, Fc-3+1+4	Fr.m-3, Fr.i-3+1, Fc-4	Fr.r-3, Fr.m-3+1, Fr.i-4	Fr.r-3, Fr.m-3+1+4	Fr.r-3+1+4	Fr.r-3+4	Fr.r-1+2		Fi-3	Fc-3	Fr.i-3, Fi-1	Fr.m-3, Fc-3+1, Fi-4
		NFIs	Fc-80	Fc-80	Fr.i-70	Fr.m-70	Fr.r-50	Fr.r-40	Fr.r-12	Fr.r-7				Fi-84
	2017-18	EFIs	Fr.m-3, Fr.i-2, Fc-5	Fr.r-3, Fr.m-2, Fc-5	Fr.r-3+2, Fr.i-5	Fr.r-2, Fr.m-5	Fr.m-5	Fr.r-5	Fr.r-2		Fi-3	Fc-3, Fi-2	Fr.i.-3, Fc-2	Fr.m-3, Fc-2, Fi-5
		NFIs	Fc-73	Fc-70	Fr.i-65	Fr.m-62	Fr.m-62	Fr.r-60	Fr.r-9	Fr.r-6				Fi-75
Site-II	2015-16	EFIs	Fr.m-4, Fc-2+6	Fr.m-4, Fr.i-2, Fc-6	Fr.r-4, Fr.m-2, Fr.i-6	Fr.r-4, Fr.m-2+6	Fr.r-3, Fr.m-6	Fr.r-6	Fr.r-2			Fi-4	Fc-4, Fi-2	Fr.i-4, Fc.-2, Fi-6
		NFIs	Fc-12	Fc-12	Fr.i-10	Fr.m-10	Fr.m-10	Fr.r-8	Fr.r-4	Fr.r-2				Fi-16
	2016-17	EFIs	Fc-5, Fr.i-5	Fr.m-5, Fc-5	Fr.m-5, Fr.i-5	Fr.r-5, Fr.m-5	Fr.r-1, Fr.m-5	Fr.r-4					Fi-5	Fc-5, Fi-5
		NFIs	Fc-8	Fc-8	Fr.i-7	Fr.m-7	Fr.m-5	Fr.r-3						Fi-9
	2017-18	EFIs	Fr.m-3, Fc-3	Fr.m-3, Fc-3	Fr.r-3, Fr.i-3	Fr.r-3, Fr.m-3	Fr.m-3	Fr.r-3	Fr.r-1			Fi-3	Fc-3	Fr.i-3, Fi-3
		NFIs	Fc-7	Fc-7	Fr.i-7	Fr.m-6	Fr.m-6	Fr.r-5	Fr.r-2					Fi-7
Site-III	2015-16	EFIs	Fr.m-2, Fc-2	Fr.m-2, Fc-2	Fr.r-0, Fr.i-2	Fr.m-2	Fr.m-2	Fr.r-2			Fi-2	Fc-2	Fr.i-2	Fr.m-2, Fi-2
		NFIs	Fc-12	Fc-10	Fr.i-10	Fr.m-7	Fr.m-6	Fr.r-3	Fr.r-1					Fi-13
	2016-17	EFIs	Fr.m-2, Fc-2	Fr.m-2, Fr.i-2	Fr.r-2, Fr.m-2	Fr.r-2, Fr.m-2	Fr.r-1+2	Fr.r-1				Fi-2	Fc-2	Fr.i.-2, Fi-2
		NFIs	Fc-11	Fc-10	Fr.i-10	Fr.m-10	Fr.r-9	Fr.r-9	Fr.r-3					Fi-11
	2017-18	EFIs	Fr.m-1, Fc-1+2	Fr.m-1, Fr.i-1, Fc-2	Fr.r-1, Fr.m-1, Fr.i-2	Fr.r-1, Fr.m-1+2	Fr.r-1, Fr.m-2	Fr.r-2				Fi-1	Fc-1, Fi-1	Fr.i-1, Fc-1, Fi-2

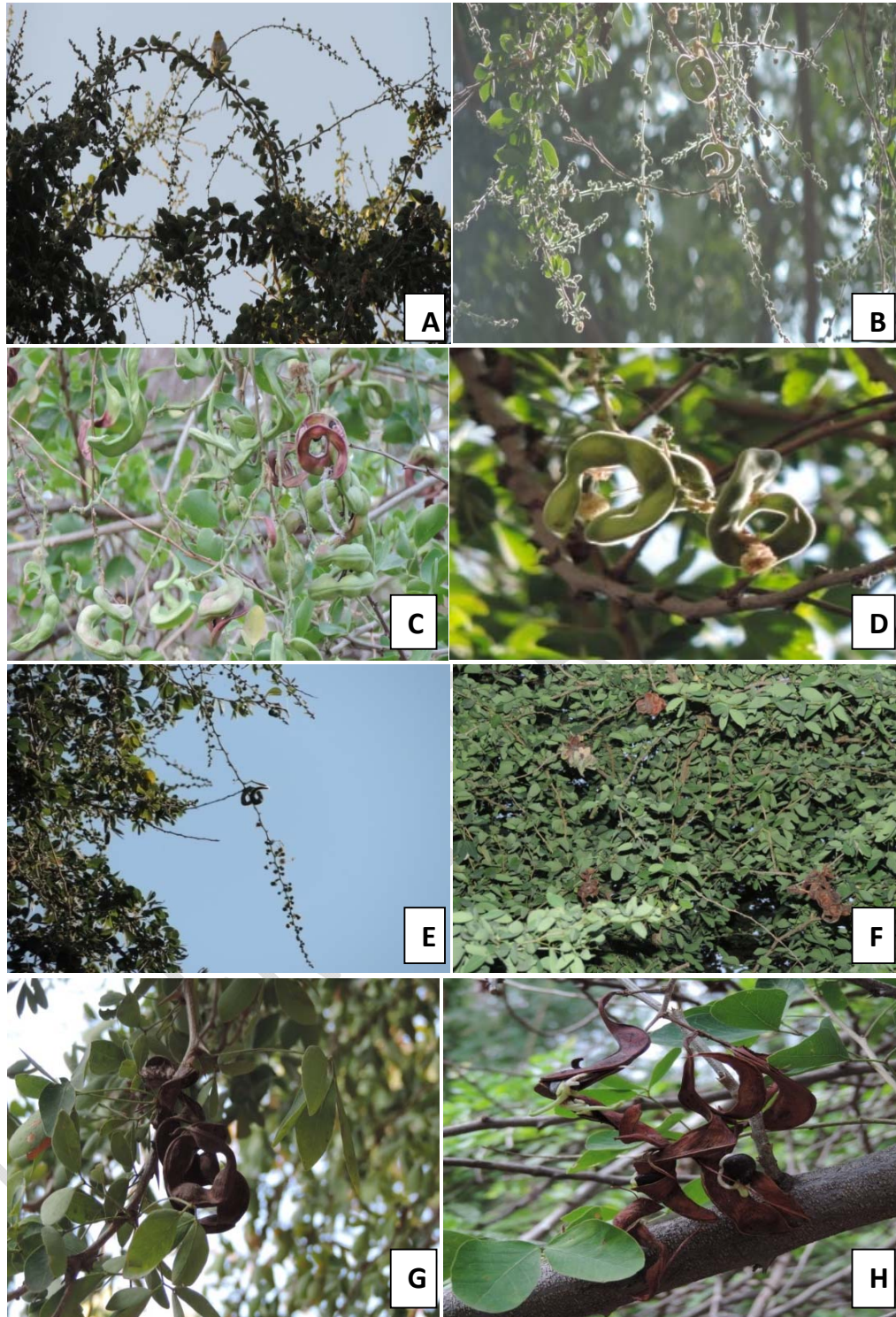


Fig. 1 Morphological descriptors of reproductive behaviour of *Pithecellobium dulce* of semi-arid climate

A. Single winter blooming tree showing synchronized floral initiation during December **B.** Early-cum-twice blooming tree showing fruits of autumn blooms along with synchronized floral initiation of winter blooms during December **C.** Shrinkage and splitting up of fruits of winter blooms during harsh summer **D.** Well developing plump fruits of autumn blooms **E.** Autumn bloom fruits entangled with winter bloom inflorescence **F.** Persistent fruits that remain attached with the parent tree throughout the year **G.** Dried persistent fruit with seeds and thin substratum within the cavity of the fruit **H.** *in situ* germination of seeds within the persistent fruit during high humid rainy season.

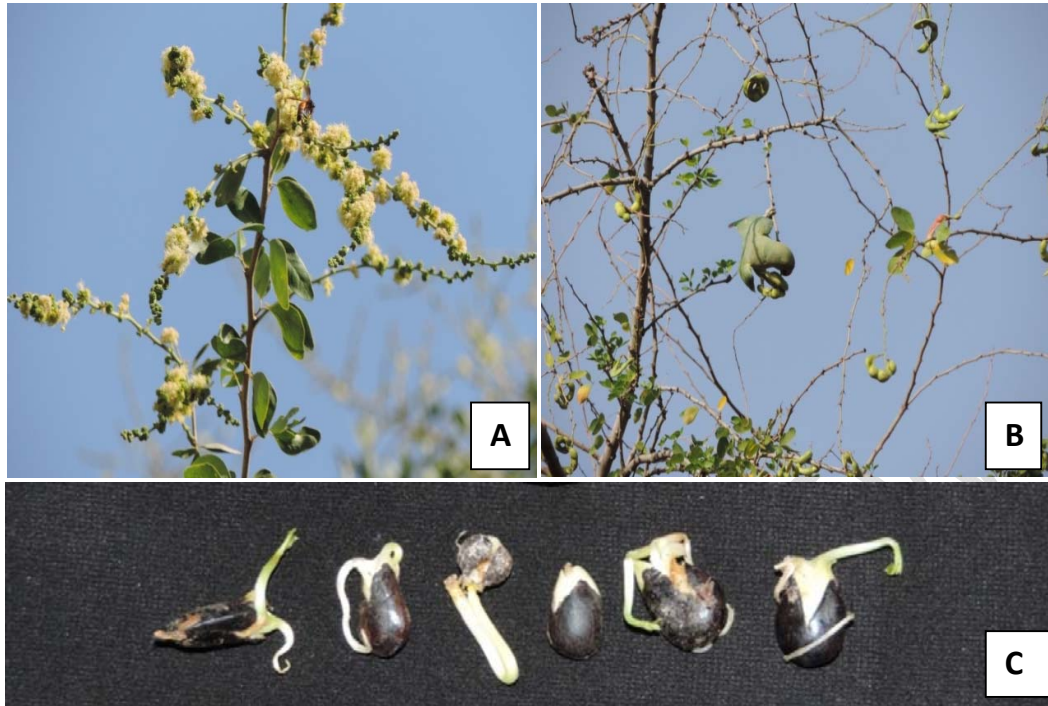


Fig. 2 Morphological descriptors of reproductive behaviour of *Pithecellobium dulce* of semi-arid climate

A. Winter bloom flowers with pollinators **B.** Dryness induced defoliation of branches with exposed fruits along with frugivores during summer months **C.** Seedling abnormalities showing constrained growth of plumules and radicles that coil around seeds during *in situ* germination within the walls of dried persistent fruits during high humid rainy days

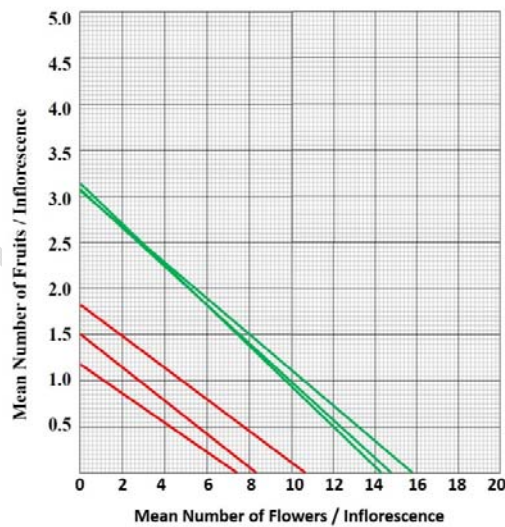


Fig. 3. Graphical representation of fruit to flower ratio of winter and autumn blooms exhibited by three individual twice-flowering trees. Autumn blooms and winter blooms have been represented through red and green lines respectively.

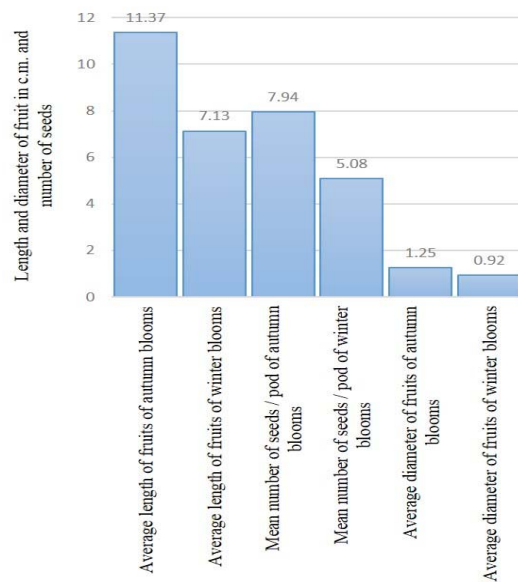


Fig. 4. Histogram showing pomometric characteristics

4. CONCLUSION

There are three categories of individual trees of *P. dulce* comprise its natural population of habitat under study of semi-arid climate with respect to their reproductive behaviour. Of all blooming trees, majority of them (89.94%) constitute category-I which exhibits normal or winter bloom in which flowering is initiated in almost synchronised manner during December and all reproductive activities including dehiscence of fruits are completed by June or July months every year. Category-II trees (7.47%) exhibit two blooms consecutively in a year, viz., early or autumn bloom and normal or winter bloom. However, their flowering-fruiting phenological onset timings of early or autumn blooms were inconsistent during the period of study. Category-III individuals (2.58%) of *P. dulce* exhibit agronomically advantageous flowering-fruiting phenophase, early or autumn blooms in these individuals were observed to be conspicuously consistent throughout the study duration. They exhibited very conspicuous early or autumn blooms in which flowering was initiated in the month of September in addition to normal or winter blooms. Overall productivity in terms of number of fruits in this category of trees is greater as compared to other two categories of trees. Though, the numerical value of fruit productivity of autumn blooms was inferior to winter blooms within the same tree, pomometric characteristics of former were superior. Moreover, the availability of fresh fruits in early-cum- twice blooming tree is also prolonged (February to July). Undoubtedly, Category-III variants or germplasm are horticulturally superior and more desirable that warrant their selection and clonal multiplication. It is evident through consistency in data in phenological calendar that early or autumn bloom in this category of individuals is not influenced by environmental variables alone, i.e., edaphic or climatic since they grow in a similar habitat, however, some age specific flowering was observed. They arose probably by expression of heterogeneity in seeds which differentiated through natural genetic recombination in response to evolutionary forces being operative under prevailing environmental conditions of semi-arid climate. The present paper also makes evolutionary predictions that how a shift in flowering phenology of *P. dulce* as exhibited by the elite variants or germplasm could have long-term implications for reshaping of future landscapes of semi-arid or arid climate through reproductive success, wide dissemination of seeds, consequently better establishment of the species. The concept of reproductive success as postulated in this paper is also expressed by Kudo, 2006 [78], and Elzinga et al., 2007 [69], that individual plants flowering for longer durations have several advantages over other members of the population with respect to higher out crossing rates owing to availability of diversities in pollinators, and more time for fruit development and seed maturation during favourable season as observed in case of autumn blooms of *P. dulce*. The present work identifies and selects agronomically valuable variants or germplasm of *P. dulce* through simple method of construction of phenological calendar. It also reports associated ecological phenomena of persistence of fruits serving as micro-habitat for breeding of insect pollinators and sporadic *in-situ* germination of seeds. Nevertheless, a great effort would be required in resolution of some inherent research possibilities arising with discovery of a new phenophasic variants such as innovation in designing agronomic practices or methods to enhance overall productivity of the cultivars through optimising the yield from early or autumn

blooms; development of macro and micro propagation protocols for enhanced multiplication of the elite variant or genotype; genetic modification of the cultivars through biotechnological interventions involving elite germplasm; and deciphering the molecular cascades for reception of altered environmental cues for phenological shift in flowering from normal or winter blooms to early or autumn blooms are relevant topics of scientific investigations which could further pave the way for molecular engineering of phytophenology as future area of promising research of far reaching consequences.

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