ICPH 2671 -THE WORLD'S FIRST COMMERCIAL GRAIN LEGUME HYBRID

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SUMMARY

Pigeonpea [*Cajanus cajan* (L.) Millsp.] is an important food legume of semi-arid tropics. In spite of releasing several varieties, its productivity has remained unchanged. To overcome this bottleneck, a commercial hybrid breeding technology, the first of its kind in any grain legume was developed. To achieve this, as a first step a stable cytoplasmic – nuclear – male –sterility (CMS) system was bred, which in combination with natural out-crossing was used to develop the hybrid technology. A breakthrough was achieved in 2005, culminating more than three decades of research, by developing a stable CMS system using the cytoplasm of a wild relative (*C. cajanifolius*) of pigeonpea. This male-sterility was transferred to diverse lines through backcrossing. Simultaneously, an efficient hybrid seed production technology was also developed. So far over 700 experimental hybrids have been tested and promising hybrids exhibited 30-100% yield advantage over control. The most promising hybrid is ICPH 2671. In multi-location testing this hybrid recorded 35.8% superiority over the ruling variety. This hybrid is also resistant to major pigeonpea diseases. ICPH 2671 performs well under moisture stress conditions and is suitable for intercropping. In 2008, this hybrid was launched for commercial cultivation in India. In the on-farm trials conducted in four provinces, mean yields of this hybrid varied from 250 to 2830 kg ha^{-1} with upto 160% advantage. The hybrid pigeonpea technology, the first of its kind in the world, has shown potential for a breakthrough in yield and soon the farmers will reap its benefits.

Key words: Pigeonpea, *Cajanus cajan*, hybrid, seed production technology, male-sterility, out-crossing.

INTRODUCTION

Most food proteins in the semi-arid tropics are derived from legumes that are generally grown under low input and risk - prone marginal environments with repeatedly low and unstable yields. At present the protein availability among masses in the developing world is less than one - third of its normal requirements and with growing population and stagnation of yield the protein availability will certainly decline further. Since food production balance always remains in favour of cereals, this issue assumes more significance from nutrition point of view. Among legumes pigeonpea (*Cajanus cajan* (L.) Millsp.) occupies an important place in rainfed agriculture. Globally, it is cultivated on 4.79 m ha in 22 countries. In Asia besides India, Myanmar (570,000 ha), China (150,000 ha), and Nepal (21,000 ha) are important pigeonpea

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growing countries. In African continent, Kenya (190,000 ha), Malawi (123,000 ha), Uganda (87,000 ha), Mozambique (85,000 ha), and Tanzania (68,000 ha) produce considerable amounts of pigeonpea. The Caribbean islands and some South American countries also have reasonable area under pigeonpea. In India, de-hulled split cotyledons of pigeonpea are cooked to make *dal* (thick spicy soup) for eating with bread and rice, while in southern and eastern Africa, and South America, whole dry and immature seeds are used as vegetable. Its nutritious broken seeds, husks, and pod walls are fed to cattle; while its dry stems make an excellent household fuel wood. Pigeonpea is credited to be the most suitable crop for subsistence agriculture because it is drought tolerant, needs minimum inputs, and can produce reasonable quantities of food even under unfavorable conditions. Its seeds contain about 20 - 24% protein and reasonable amounts of essential amino acids.

The Problem of Yield Plateau in Pigeonpea

In India, where 76% of global pigeonpea production is confined, the new cultivars are attracting rainfed farmers and consequently the cropped area has increased from 2.3 m ha in 1950 to 3.53 m ha in 2007. Unfortunately, no increase has been witnessed in its productivity (yield kg ha^{-1}), which in the past five decades has remained stagnant at around 700 kg ha^{-1} (Fig 1). There may be various factors responsible for the low productivity but the lack of high yielding cultivars has been identified as the major factor underlying this bottleneck. To overcome this constraint Indian Council of Agricultural Research (ICAR) initiated a multi-disciplinary pigeonpea improvement programme in 1967 in all the major agro-climatic zones of India. This mega project has so far released more than 100 pure line varieties which helped in increasing pigeonpea area and production but without any change in the productivity. The issue of productivity plateau has been a major concern for a long time and to date it has remained a challenge.

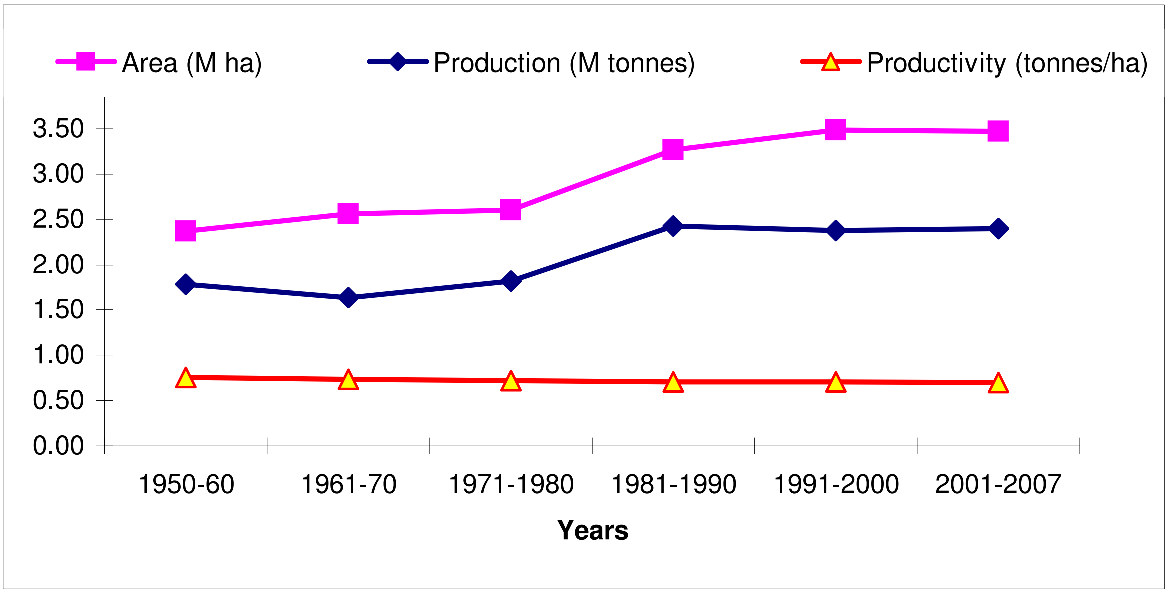

Fig.1. Area, production, and productivity of pigeonpea in the last five decades

The quantum jumps in yields recorded in some cereals, vegetables, and fruit crops are primarily attributed to the development of high yielding hybrids. To achieve a similar breakthrough in pulses, the deployment of a non-conventional breeding approach is also warranted. In this group of crops the hybrid breeding approach could not be exploited earlier due to their highly self-pollinating nature and inability to produce hybrid seed economically. Faba bean (*Vicia faba*) and pigeonpea are the two exceptions where reasonable level of natural out-crossing occurs and this offered opportunities to breed hybrids. In faba bean such efforts were unsuccessful due to technical limitations in large-scale hybrid seed production (Bond *et al.*, 1966). In pigeonpea, the concept of hybrid breeding using its natural out – crossing and male - sterility systems was initiated by ICRISAT. In the last few years significant progress has been made to breed and take the hybrid technology to Indian farmers. Most of the major issues related to large-scale hybrid seed production have been solved and now this technology is ready for seizing by the seed sector and farmers. This paper briefly discusses the main features of this technology and its prospects to enhance pigeonpea productivity.

Hybrids - a new breeding technology in pigeonpea

Shull (1908) was the first to describe the phenomenon of hybrid advantage in crop plants and considering its potential in enhancing yields. Subsequently, the breeders of cross - pollinated crops developed suitable breeding procedures and successfully enhanced yields by 2 – 3 fold. Sinha and Khanna (1975) and Srivastava (1981) reviewed various theories proposed to explain the complex phenomenon of heterosis and concluded that some complementary inter - genomic and non - allelic interactions, operating at different structural and functional levels, are responsible for the expression of hybrid vigour. The differences observed for hybrid vigour in reciprocal crosses also emphasized the importance of cytoplasmic - nuclear interactions in the expression of heterosis. Since dominant genes are known to have evolutionary advantage, the heterosis was initially considered a discernible phenomenon of only cross - pollinated crops but later its utility in self - pollinating crops was also established. Sharma and Dwivedi (1995) suggested that besides over - dominance and dominance, additive and additive x additive inter - allelic and inter - genomic interactions also play an important role in the expression of hybrid vigour. The likelihood of obtaining heterotic cross combinations in pigeonpea is high because it has an inherent capacity to carry a considerable hidden genetic load of recessive genes due to its partial out - crossing nature and with a little effort breeders can make use of it in enhancing yield. A review of literature in pigeonpea showed that important economic traits such as yield, pods plant^{-1}, plant height, seed size, and seeds pod^{-1} are controlled by both additive as well as non - additive gene actions (Saxena and Sharma, 1990) and the level for hybrid vigour for yield is comparable with other crops where commercial hybrids have already been successful. For a successful commercial hybrid pigeonpea programme the following are pre–requisites:

Presence of hybrid vigour for seed yield

Although pigeonpea breeding research began in the early part of 20th century, the first report of hybrid vigour was published by Solomon *et al.* (1957). Subsequently, a number of reports were published on hybrid vigour for yield and important yield components (Saxena and Sharma, 1990). Earlier in the absence of CMS in pigeonpea, an attempt was made to exploit hybrid vigour using genetic male-sterility based hybrids such as ICPH 8, PPH 4, CoH 1, CoH 2 etc (Saxena *et al.*, 1992). These hybrids exhibited 20 to 40% superiority over the respective control cultivar in farmers' fields. Kandalkar (2007) reported that CMS-based hybrids exhibited standard heterosis up to

156% for yield where as Saxena (2007) reported yield advantage of 50 to 100% over the controls.

Mass pollen transfer mechanism

Unlike other legumes, there is a considerable extent of insect mediated natural out-crossing in pigeonpea. Its extent primarily depends on the number of pollinating insects (Saxena *et al.*, 1990). The experiments conducted at ICRISAT have shown that the out-crossing of about 25% is sufficient to produce hybrid seed economically (Saxena, 2007).

Cytoplasmic - nuclear male-sterility systems

It was in 1974 when pigeonpea breeders at ICRISAT started exploring the possibility of breeding commercial hybrids by exploiting its natural out - crossing. The major component for commercial hybrid breeding that was missing at that time was the availability of an efficient male - sterility system. Therefore, an extensive search for male - sterility was made in the germplasm and two different genetic male - sterility systems were discovered (Reddy *et al.*, 1978; Saxena *et al.*, 1983). Initially, these two sources were used in hybrid breeding without much success at the commercial level due to limitations encountered in large - scale seed production of hybrids and their parents. Hence, the development of a CMS system became imperative.

The expression of CMS, in part, is controlled by genetic factors carried through the female parent, which are never lost or diluted in succeeding generations. This cytoplasmic factor is referred to as 'N' for male - fertile cytoplasm and 'S' for the male – sterile cytoplasm. The male - sterile (A-line) line with 'S' cytoplasm and homozygous recessive (*msms*) nuclear genes is maintained by its male – fertile maintainer (B-) line that has a normal (N) cytoplasm and homozygous recessive nuclear genes. To produce male - fertile hybrids, the A - line with 'S' cytoplasm is crossed with a male - fertile (R–) line carrying dominant fertility restoring nuclear genes (*FrFr*). To sum up, the three - line hybrid system is geared for multiplying A-line seed with the help of B-line and for producing hybrid seed the A-line is pollinated with R-line.

In pigeonpea since CMS was not available, plans were made to breed for this trait by placing pigeonpea genome in to the cytoplasm of its wild relative. It was expected that the interaction of such cytoplasm and nuclear genomes would produce male - sterility that would inherited maternally. This endeavour resulted in development of an excellent CMS system that was developed by crossing a pigeonpea line with a wild species, *Cajanus cajanifolius*. It is the most closely related wild species of pigeonpea and is considered as the progenitor of cultivated type that differs only by a single gene (De, 1974). The CMS system derived using this species (Saxena *et al.*, 2005) is considered the best because it has a number of good maintainers and fertility restorers. The F_1 hybrid plants produce excellent pollen load and pod set. The A- lines with *C. cajanifolius* cytoplasm are being used extensively in hybrid breeding programmes.

Hybrid Seed Production Technology

An efficient seed production system that could provide quality seeds at economically viable costs is the backbone of any hybrid technology. The benefits of new hybrids cannot be realized unless sufficient quantities of pure seeds are commercially produced and sold at a cost affordable to farmers.

Since pigeonpea flowers are prone to natural out-crossing, a safe isolation distance is essential to produce quality seed of hybrids and their parents. The commercial seed production of pigeonpea hybrids involves large scale seed production of female (A-) line maintainer (B-) line, restorer (R-) line, and hybrid combination (A x R). For purity maintenance each set of material demands isolation distance of at least 500 m or more. For seed increase of A-line, breeder seed of both A- and B- lines are planted at the same time using a female:male row ratio ranging from 4:1 to 8:1. In case of higher insect activity an 8:1 ratio also gives good seed yield, whereas the 4:1 row ratio gives optimum yield at most locations. For hybrid seed production (A x R) also, the row ratios may vary, as above. Timely roguing and strict crop monitoring are critical for seed production. In general, roguing of off-type plants is done at seedling and flowering stages. The available plants descriptors can also be used for effective roguing. Seed production trials conducted for two seasons at ICRISAT have given encouraging results and on average 1135 kg ha^{-1} seed of A-lines (A x B) was harvested (Saxena, 2007). Similarly for hybrids (A x R), an average of 975 kg ha^{-1} yield was recorded.

ICPH 2671 – a hybrid with high performance

Important characteristics of hybrid ICPH 2671

Plants of ICPH 2671 are semi-spreading and indeterminate in growth habit, which achieve a mean height of about 223 cm at maturity. On average, it flowers in 114 – 120 days and its 75% pod maturity is achieved in 166-184 days (Table 1). The flowers of ICPH 2671 are yellow with dark red streaks on their petals. The pods of this hybrid are dark purple in colour and on average contain 3.7 - 4.0 dark brown and round seeds. Its 100 seeds weigh between 10.5 to 11.2 g. Its plants are photo-sensitive and plastic in nature responding positively to wider spacings. ICPH 2671 is highly resistant to Fusarium wilt and sterility mosaic diseases. Its flowers and pods are susceptible to *Helicoverpa* pod borer attack.

On – station performance of ICPH 2671

The first on-station yield trial of ICPH 2671 was conducted in 2004 at Patancheru where it produced 2444 kg ha^{-1} grain yield with 28.3% superiority over the national check variety Maruti. From 2005 to 2008 this hybrid was tested in multi-location trials (Table 1). Its mean performance in different years ranged from 2022 to 3183 kg ha^{-1} and on average recorded 35.8% superiority over the national check variety Maruti. In 2008, an early season drought that was followed by heavy rains resulted in low yields of both hybrid and control. In the All India Advanced Hybrid Trials conducted at six locations in 2007, ICPH 2671 recorded 34.7% yield advantage (Table 2) over the control variety with yield ranging from 1770 to 3583 kg ha^{-1}.

On-farm performance

In 2007, a total of 29 demonstrations were conducted in farmers' fields in 0.2 to 0.4 ha plots in four provinces. The mean superiority of hybrid ICPH 2671 at different locations ranged from 8.3 to 85.7%. Highest yield (2588 kg ha^{-1}) was recorded in Madhya Pradesh (Table 3) with 34.4% yield advantage.

In 2008, the number of on-farm tests of ICPH 2671 was extended to 637 in 19 locations of four provinces (Table 4). In Maharashtra (44 trials), the mean yield advantage of hybrid was 28.2%, while in Andhra Pradesh (299 trials), the hybrid exhibited 17.5% superiority over the control. Similarly in Karnataka (14 demonstrations) and Madhya

Pradesh (280 demonstrations) the hybrid out-yielded the control by margin of 18.9 and 25%, respectively.

Over all the 637 on-farm trials, conducted on 220 ha in total, the hybrid ICPH 2671 exhibited 22.6% superiority over the control cultivar Maruti. In Hoshangabad (Madhya Pradesh) the hybrid recorded highest (2830 kg ha^{-1}) yield and it was 32% superior to the local check.

Advantages of Pigeonpea Hybrids

Increased plant vigour and reduced seed rates

Inherently, pigeonpea is a slow growing plant particularly in its early stages which makes it a poor competitive with weeds. In comparison to traditional cultivars the hybrids have greater plant vigour (Saxena *et al.*, 1992) which helps them in quick establishment and competitiveness. This attribute of hybrids also make them suitable for inter-cropping. In an experiment at ICRISAT it was found that one month old seedlings of hybrids produced 43.9 % higher shoot and 42.8 % higher root mass than traditional cultivars. In cereals, a considerable proportion of yield variation among genotypes is attributed to the differences in partitioning of the carbohydrates but in pigeonpea such variations are due to the differences in crop growth rates (Chauhan *et al.*, 1994). The higher crop growth rates of pigeonpea hybrids eventually result in high biomass production and more grain yield. Total biomass production in excess of 20 t ha^{-1} has been recorded in hybrids in subtropical environments. A significant proportion (18 - 20%) of this biomass is returned to the soil in the form of fallen leaves thus contributing to the pool of organic matter. Pigeonpea hybrids also produce more primary and secondary branches with a wider canopy and greater plasticity without adversely affecting yield. This helps in reducing the seed rate by 40 - 50% compared to traditional varieties. This will offset the higher seed cost which farmers pay to buy hybrid seeds.

Greater drought tolerance

In comparison to pure line cultivars, pigeonpea hybrids, by virtue of their greater root mass and depth, possess greater ability to draw water from deep soil profiles. Their fast root growth also helps plants tide over early season drought conditions. Since pigeonpea is generally grown as a rainfed crop, it is subjected to both intermittent and terminal droughts. In general, the short duration varieties are more prone to drought because of fewer roots and under such situations, the short duration hybrids with greater root mass always perform better than pure line varieties. In addition to root traits, the hybrids also maintain relatively high water content under adverse conditions, which contribute to their enhanced drought tolerance (Lopez *et al.*, 1996).

Greater disease resistance

Fusarium wilt and sterility mosaic are major pigeonpea diseases and together they cause major yield losses every year. Results of experiments conducted at ICRISAT showed that disease resistant hybrids offer more resistance to the attack of causal organisms than resistant pure line cultivars by virtue of their greater resilience (Saxena *et al.*, 1992). Evaluation of disease resistant pigeonpea hybrids and pure line cultivars showed that under high disease pressure, both the hybrids as well as pure line cultivars, exhibited similar (<1%) disease incidence but the expression of hybrid vigour differed significantly. The hybrids exhibited 19.7% superiority over pure line cultivars under disease - free conditions but the level of superiority of hybrids under disease - sick conditions was more than 60%. It, therefore, appears that in addition to the specific antifungal/viral resistance mechanisms, the hybrids have an extra degree of genotypic plasticity which helps them to resist diseases better in comparison to pure lines. In general, the hybrids also express better environmental buffering capacity compared to pure line cultivars. Therefore, the yield fluctuations brought about by various stresses could be reduced by cultivating pigeonpea hybrids.

GENERAL DISCUSSION

Even after centuries of cultivation and natural selection pigeonpea continues to remain a wild plant with its unique characteristics such as perennial and indeterminate growth habit, low harvest index, and photo - thermal sensitivity. Its ability to survive and produce food even under high stress conditions has helped subsistence farmers and even today pigeonpea is considered as the most ideal crop of small-holding rainfed farmers. In recent years, pigeonpea production has undergone significant growth and it is primarily attributed to the development of new disease resistant varieties. Since the demand for pigeonpea is ever increasing and the scope for area expansion is limited, the attention is now focusing on increasing its yield potential. The pure line variety breeding programme that was implemented decades ago did not produce desired results and the crop yields remained consistently low. The development of CMS system and natural cross pollination has opened a new option to breeding hybrids in pigeonpea for enhanced yield potential.

The CMS-based hybrid pigeonpea technology is now ready for take off with all its major components in place. However, considering a vast variation in agro - ecological conditions, fine tuning of the seed production technology is essential to suit local environments. The level of yield superiority observed in hybrids conclusively demonstrated that they have higher yield potential. Now, our major responsibility is to take this new research product to the clients - the farmers. Considering the potential of this technology and excellent prices, it is expected that farmers with both small as well as large holdings will adopt the hybrids. It is also important to keep the hybrid seed costs within the reach of resource poor farmers. In India, both public and private seed sectors are strong and these resources are being used to improve the accessibility of high yielding hybrid seed to farmers.

It has been observed that the magnitude of realized heterosis for yield in pigeonpea is more or less similar to those of other crops. Therefore, it can be exploited commercially in pigeonpea since a grower - friendly mass hybrid seed production technology is now available. It is believed that in pigeonpea, the first breakthrough in yield will come only from the hybrids. In this endeavour a good beginning has been made and soon farmers will reap the benefits of this technology.

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Table 1. Summary performance of hybrid ICPH 2671 and control cultivar Maruti in multi-location trials conducted from 2005 to 2008.

Traits	2005 (n=5)	2006 (n=5)	2007 (n=11)	2008 (n=22)	Mean (n=43)	Superiority of hybrid (%)
Yield (kg ha^{-1})						
Hybrid	3183	2694	2702	2022	2650	35.8
Control	1855	2066	2140	1746	1952	
Seed size (g 100^{-1} seeds)						
Hybrid	11.2	10.9	10.8	10.5	11.0	
Control	10.3	10.4	10.3	10.1	10.0	
Maturity (days)						
Hybrid	181	184	180	166	178	
Control	178	175	174	162	172	
Flowering (days)						
Hybrid	120	119	116	114	117	
Control	123	118	115	111	117	
Plant height (cm)						
Hybrid	226	215	222	227	223	
Control	199	205	213	218	209	
Seeds pod^{-1}						
Hybrid	3.7	3.8	4.0	4.0	3.9	
Control	3.7	3.8	3.7	3.9	3.8	

n=number of locations

Table 2 : Yield of hybrid ICPH 2671 at six locations in All India Advance Hybrid Trials, 2007

Location	Yield (kg ha^{-1})		Superiority of hybrid (%)
	ICPH 2671	Maruti	
S K Nagar	2937	2169	35.4
Rahuri	2590	2660	(-) 2.6
Khargaon	3029	2180	38.9
Coimbatore	1028	823	24.9
Warangal	3583	1549	131.3
Patancheru	1770	1707	3.7
Mean	**2490**	**1848**	**34.7**

Table 3. Performance of ICPH 2671 in on-farm trials conducted in 2007

Location	Trials	Yield (kg ha^{-1})		Superiority of hybrid (%)
		ICPH 2671	Maruti	
Pradham Bio-tech, Karnataka	1	1200	700	71.40
SFCI, Jawalgera, Raichur	1	650	350	85.70
Mahyco, Karnataka	6	1700	1570	8.28
Mahyco, Maharastra	13	1820	1588	14.61
SFCI,BV Nagar, Nandyal	1	2500	1875	33.33
Mahyco. Andhra Pradesh	5	2020	1710	18.12
Mahyco, Madhya Pradesh	2	2588	1925	34.40
Total/mean	**29**	**1783**	**1388**	**28.45**

Table 4: Yield of hybrid ICPH 2671 in on-farm trials conducted in 2008

Location	No. of farmers	Area (ha)	Yield (kg ha^{-1})		Mean check yield (kg ha^{-1})	% Superiority of hybrids
			Mean	Range		
Maharashtra						
Kanzara	5	2.0	1179	312 – 2778	779	**51**
Kinkhed	3	1.2	580	158 – 748	516	**12**
Shirapur	4	1.6	825	433 – 1700	525	**57**
Kalman	9	3.6	1241	638 - 2750	525	**136**
Osmanabad	4	1.6	1230	950 -1300	1175	**5**
Beed	4	1.6	1179	870 -1150	1020	**16**
Latur	3	1.2	955	800 - 1200	890	**7**
Parbhani	12	4.8	1358	810 - 1610	1232	**10**
Total/mean	**44**	**17.6**	**1068**	**158 - 2778**	**833**	**28.2**
Andhra Pradesh						
Guntur	40	16.0	1125	NA	1050	**7**
Medak	22	20.0	1106	NA	609	**82**
Ananthpur	100	40.0	568	NA	488	**16**
Cudappah	50	20.0	250	NA	225	**11**
Ranga Reddy	30	12.0	1250	NA	1200	**4**
Chittoor	40	16.0	581	NA	538	**8**
Nalgonda	17	6.8	663	NA	609	9
Total/mean	**299**	**130.8**	**792**	**NA**	**674**	**17.5**
Karnataka						
Gulbarga	**14**	**5.6**	**1131**	**NA**	**951**	**18.9**
Madhya Pradesh						
Betul	200	40.0	814	NA	745	**10**
Hoshangabad	50	20.0	2830	NA	2150	**32**
Chicholi	30	6.0	825	NA	682	**21**
Total/mean	**280**	**66.0**	**1490**	**NA**	**1192**	**25.0**
Grand total/mean	**637**	**220**	**1120**	**-**	**913**	**22.6**