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# Detection of biennial rhythm and estimation of repeatability in mango (*Mangifera indica* L.)

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**Abstract**

**Most of the perennial crops exhibit biennial rhythm in fruiting and growth. Among the perennial crops, mango is an important fruit crop not only in India but also across the world. This crop acquires bienniality, a complex phenomenon, by carrying a heavy fruiting in one year called 'on' year and little or no fruiting in the next year called 'off' year. The presence of bienniality in the data may affect genetic parameter estimates like repeatability. In this paper, the extent and intensity of bienniality in mango has been studied by graphical as well as quantitative approaches. Besides, a test of significance for bienniality has been obtained for each tree using binomial distribution. On this basis, the percentage trees in 'on' years and in 'off' years has been quantified for four different locations. Also, variety-wise biennial rhythm has been studied in these locations. The results reveal that there exists a moderate to strong bienniality in mango crop. Besides, the errors become auto-correlated when bienniality is removed by taking moving average. Moving average methods have been applied to estimate the repeatability. The results reveal that the mango yield was moderate to highly repeatable.**

Key words: Bienniality, perennial crops, mango, repeatability, Auto-correlation.

## Introduction

Mango (*Mangifera indica* L.) is one of the most important perennial fruit crops grown in many tropical and subtropical countries (Mukherjee and Litz 2009). Mango fruit is also called as 'king of fruits' in India due to its sweetness, richness of taste, huge variability, large production volume and variety of usages. India is the largest producer of mango in the world, with an annual production of 15.03 million tons from an area of 2.31 million hectares (FAOSTAT 2011) contributing about 56% of the total world production. A large number of varieties of mango exist in India and they contribute 39.5% of the total fruit production in the country. Fresh fruit of mango is used in various forms such as pickle, chutney, jam, jelly, while mango shake is a popular drink throughout the world. It is an excellent source of Vitamins A, C, D, B6, B12 and minerals like K, Cu, Mg, Mn.

Most of the perennial species including mango exhibits biennial rhythm in cropping and growth (Pearce 1953; Monelise and Goldsmith 1982). Singh (1948) explained the biennial rhythm in fruit trees as 'on' year when trees carry heavy crop and 'off' year when they carry little or no crop. This complex phenomenon is also called as bienniality or alternate bearing. Webester (1939) and Nakasone et al. (1955) reported the presence of biennial tendency in palm and mango fruit trees respectively. The major causes of alternate bearing in fruit crops are carbohydrate depletion during 'on' year, hormonal activity, genes regulating flowering, climate events, overloading of fruits during 'on' year etc. Lavee (2007) found that the main endogenous and environmental factors and their interactions lead to the alternate bearing in olive. Krishnamurthy et al. (2013) studied the influence of carbohydrate, minerals and hormones (IAA and zeatin riboside) on alternate bearing in black pepper (*Piper nigrum* L). Nafeez et al. (2013) reported sustainable yield can be obtained in mango by managing irregular bearing through foliar spray of urea. However, such management is feasible only when bienniality is detected and estimated precisely.

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For understanding and measuring the biennial bearing tendency in mango, various indices of bienniality, *viz*., 'B' factor i.e., percentage of occasions where yield trends are irregular (100% full to 0% lack of bienniality), 'I' factor (intensity of deviation in yield during successive years) were proposed by Hoblyn et al. (1936). The indices given by Hoblyn et al. (1936) renamed as Biennial Bearing Index (BBI) by Wilcoxon (1944). Abeywardena (1962) applied these measures in coconut and reported two-third Palm trees show bienniality in bearing on the basis of 'I' factor and 38.5 % palm trees exhibits significant bienniality on the basis of 'B' factor. Previously, 'I' factor is used to detect bienniality in apple (Barrit et al. 1997), guava and orange (Wahi and Malhotra 1993), Pistachio (Rosenstock et al. 2010) and citrus (Smith et al. 2004). Mango being a commercial fruit crop, it has a large dimension of economic and academic importance to study the biennial rhythm. The presence of bienniality affects the estimation of yield production and other genetic parameters like heritability, repeatability etc. It also, results in surplus and deficits in production and affects many factors of crop management including: price, marketing, quality, demands for labour (Kallsen et al. 2007) and nutrient uptake (Rosecrance et al. 1998). Repeatability is an important genetic parameter, which measures the extent to which differences between individuals depend on genetic and permanent environmental effects rather than those which are temporary (Turner and Young 1969). Since numerical measures of bienniality have not been fully studied in Indian mango yet, an attempt has been made in the present study to quantify and confirm the presence of bienniality. Graphical representation and numerical measures like 'B' factor and 'I' factor have been used to evaluate the presence of bienniality in mango. Equiprobable null hypothesis has been tested for the confirmation of biennial rhythm in mango fruiting. The assumption of independence of error for usual linear model has been tested for two cases (i) for data with bienniality and (ii) for data after elimination of bienniality by taking moving average of two consecutive years. Also, repeatability has been estimated for the trait: number of fruits per tree in these two cases.

## Materials and methods

Mango varieties tested in four locations namely, Rewa (Madhya Pradesh), Sangareddy (Andhra Pradesh), Vengurla (Maharashtra) and Sabour (Bihar) over different years were collected from All India Coordinated Research Project on Sub-Tropical Fruits (AICRP-STF), Central Institute for Subtropical Horticulture (CISH), Lucknow. Data for Rewa centre consists of 17 genotypes for 12 years from 1997-2008, Sangareddy centre consists of 16 genotypes for 16 years from 1992 to 2005, Vengurla centre consists of 16 genotypes for 16 years from 1990 to 2005 and Sabour centre consists of 20 genotypes for 8 years from 1993 to 2000. The Multi-Location Trials were conducted in Randomized Complete Block Design (RCBD) with four replications having two trees per replication. In the present study the number of fruits per tree has been considered as trait for the detection of bienniality and estimation of repeatability.

### *Estimation of bienniality*

Hoblyn et al. (1936) introduced 'B' factor that indicates the extent to which the cropping performance of a tree is regularly annual, biennial or irregular. The 'B' factor is determined from crop records available for at least three years. If the next year yield exceeds the previous year's yield, the difference is given a plus (+) sign otherwise, a minus sign (-). Based on this principle, a series of signs for each consecutive pairs of years was obtained from the mango data. From this series, the 'B' factor was calculated by determining the percentage of consecutive pairs of unlike signs over the whole period. A value of 'B'=100 indicates a complete bienniality in a given tree, whereas 'B'=0, indicates either regular increase or regular decrease in yield. The 'B' factor was obtained based on ($n$-2) pairs of unlike signs, where $n$ is the number of years. On the basis of an equiprobable hypothesis, i.e., the probability of unlike signs in any pair of consecutive years is 0.50, a test of significance for bienniality has been done by calculating the Binomial probabilities given by:

$$P(x) = \binom{m}{x}\left(\frac{1}{2}\right)^{x}\left(\frac{1}{2}\right)^{m-x} \quad (1)$$

where, $x$ is the number of pairs of unlike signs ($x$ = 0, 1, 2, 3, 4,…, $m$

The 'I' factor (Hoblyn et al. 1936) was employed as a measure of intensity or degree of crop fluctuations from year to year. 'I' is expressed as:

$$\text{I} = \frac{\text{Difference between successive yields}}{\text{Sum of successive yields}} \quad (2)$$

The value of 'I' vary from 0 to 1, where I=0 denotes equal crops in successive years i.e. regular bearing and I=1 denotes no crop at all in alternate years. The value of 'I' was averaged over for a number of years to obtain the percentage mean value.

***Auto-correlation***

One of the important assumptions under the ordinary least square (OLS) method for estimation of parameters is that successive values of errors are independent. However, the error terms become auto-correlated with lag one when the effect of bienniality was eliminated. The significance of auto-correlation was further tested by Box-Ljung test (Ljung and Box 1978). The estimate of first-order linear auto-correlation ( $\hat{\rho}$ ) is given by

$$r_{e_t e_{t-1}} = \frac{\Sigma r_{e_t e_{t-1}}}{\sqrt{\Sigma e_t^2 e_{t-1}^2}} = \hat{\rho}_{e_t e_{t-1}} \tag{3}$$

where $e_t$ represents the residual at $t^{th}$ period and $e_{t-1}$ is the residual at $(t-1)^{th}$ period.

The Box-Ljung test statistic is given by

$$Q = n(n+2)\Sigma_{l=1}^{h} \frac{\hat{\rho}_l^2}{n-l} \sim \chi_h^2 \tag{4}$$

where, $n$ is the sample size, $h$ is the number of lag for being tested, $\hat{\rho}$ is estimated auto-correlation with lag $l$.

***Estimation of repeatability***

Analysis of Variance (ANOVA) is one of the commonly used methods for estimating the repeatability. The procedure is given below:

Consider a linear model

$$y_{ij} = \mu + g_i + t_j + e_{ij} \qquad i = 1, 2, ..., n; \quad j = 1, 2, ..., \tag{5}$$

where $y_{ij}$ is the response (say yield) of $i^{th}$ tree at $j^{th}$ time period, $\mu$ is the general mean, $g_i$ is the $i^{th}$ tree effect, $t_j$ is the $j^{th}$ period effect and $e_{ij}$ random error distributed normally with mean zero and constant variance $\left(\sigma_e^2\right)$.

After suppressing the fixed time effect, the model reduces to

$$y_{ij} = \mu + g_i + e_{ij} \qquad i = 1, 2, ..., n; \quad j = 1, 2, ..., k. \tag{6}$$

Based on model (6), the between trees mean sum of square (MSG) and within tree mean sum of square (MSE) respectively were computed. The estimators of $\sigma_e^2$ and $\sigma_g^2$ are obtained by equating the mean squares of each source of variation to its expectation. The estimators are

$$\hat{\sigma}_e^2 = MSE; \hat{\sigma}_g^2 = (MSG - MSE)/k \tag{7}$$

Finally, the repeatability ( $\hat{\rho}$ ) was estimated as

$$\hat{\rho} = \hat{\rho}_g^2 / \left(\hat{\rho}_g^2 + \hat{\rho}_e^2\right) \tag{8}$$

with variance

$$V(\hat{\rho}) = \frac{2[1+(k-1)\hat{\rho}]^2 (1-\hat{\rho})^2}{k(k-1)(n-1)} \tag{9}$$

***Moving average based repeatability estimator –I (MA-I)***

The procedure given by Wahi and Malhotra (1993) to estimate the repeatability by eliminating bienniality in the data is given bellow:

The standard linear model for describing yield of an individual tree along with a fixed biennial effect 'b' is given as

$$y_{ij} = \mu + g_i + t_j \pm b + e_{ij} \qquad i = 1, 2, ..., n; \quad j = 1, 2, ..., k. \tag{10}$$

where, all the terms in the model (10) have the same meaning as given in model (5) except the fixed biennial effect 'b'. Suppressing the time effect ($t_j$) in eq. (10) the model reduced to:

$$y_{ij} = \mu + g_i \pm b + e_{ij} \tag{11}$$

Taking moving average of the two consecutive years, the fixed biennial effect will be eliminated but at the same time the errors become correlated with the following structure.

$$y_{ij}(c) = \frac{\left(y_{ij} + y_{ij+1}\right)}{2} = \mu + g_i + \frac{\left(e_{ij} + e_{ij+1}\right)}{2} \tag{12}$$

The estimator of $\sigma_e^2$ and $\sigma_g^2$ are:

$$\hat{\sigma}_e^2 = \frac{2(k-1)}{(k-2)} MSE; \tag{13}$$

$$\hat{\sigma}_e^2 = (MSG - MSE)/(k-1) \quad (14)$$

The final expression for estimate of repeatability is given by

$$\hat{\rho}_{MA-1} = \frac{(MSG - MSE)}{MSG + \left[\frac{2(k-1)^2}{k-2} - 1\right]MSE} \quad (15)$$

with variance

$$V(\hat{\rho}_{MA-1}) = \frac{2[1+(k-2)\hat{\rho}_{MA-1}]^2(1-\hat{\rho}_{MA-1})^2}{(k-1)(k-2)(n-1)} \quad (16)$$

***Moving average based repeatability estimator-II (MA-II)***

Another estimator proposed by Wahi and Malhotra (1993) was used to estimate repeatability in mango. The estimator along with its variance is given below:

$$\hat{\rho}_{MA-II} = MSG - \left(\frac{2k-3}{k-3}\right)MSE /$$

$$\left(MSG + \frac{1}{k-2}\left[(k-2)^2 + (k-1)^2\right]MSE\right) \quad (17)$$

and its variance expression is given by

$$V(\hat{\rho}_{MA-1}) = \frac{8(k-1)^4(k-2)^2A^3B^2}{[(k-2)A + \{(k-2)^2 + (k-2)^2\}B]^4}$$

$$\left[\frac{n(k-1)+3}{(n+1)\{n(k-2)+2\}}\right] \quad (18)$$

where, $A = MSG$ and $B = MSE$ obtained from the model (12).

**Results and discussion**

In this study, graphical as well as numerical methods have been used to confirm bienniality in mango. Graphs for the number of fruits per tree over years have been plotted separately for four centres for all the tested genotype (Figs. 1 to 4). The trend in these figures clearly indicate that the considered genotypes of mango exhibit biennial rhythm at all the centres. It has been observed that in a given centre, the pattern of bienniality exhibited by different genotypes were similar indicating that most of the genotypes are in 'on' phase in a particular year and in 'off' phase in the next year. This may be due to the reason that at a given centre trees were planted at the same time *i.e.* having same age and receiving same management practices. This pattern is more prominent at Sabour whereas it is less at Vengurla (Figs. 1 to 4). In case of Sabour, the number of fruits per tree for all the varieties during 1999 is found to be higher than in the previous years. Also, the reduction in the number of fruits per tree from 1999 to 2000 is less except for Banganpalli. This may be due to influence of favourable weather conditions for fruiting.

The number and percentage of trees in 'on' phase and trees in 'off' phase in different years are presented in Table 1. The results reveal that percentage trees in 'on' phase varies highly from year to year over locations. Particularly at Rewa centre the percentage trees in 'on' phase ranges from 3.57 to 95.54 whereas at Sangareddy from 25.6 to 79.1, Vengurla from 27.14 to 68.57 and at Sabour from 0 to 100 per cent. It has

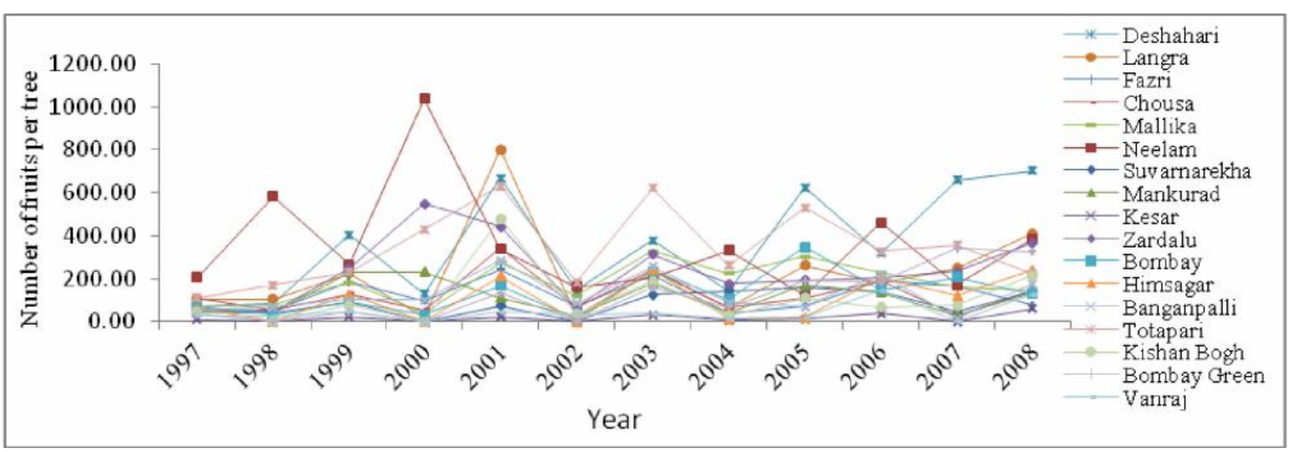


**Fig. 1. Number of fruits per tree from 1997 to 2008 at Rewa centre for 17 varieties**

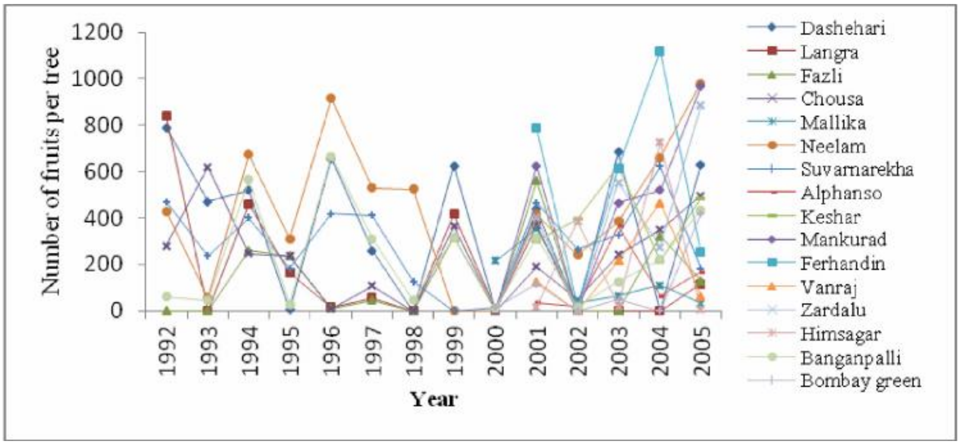


**Fig. 2. Number of fruits per tree from 1992 to 2005 at Sangaready centre for 16 varieties**

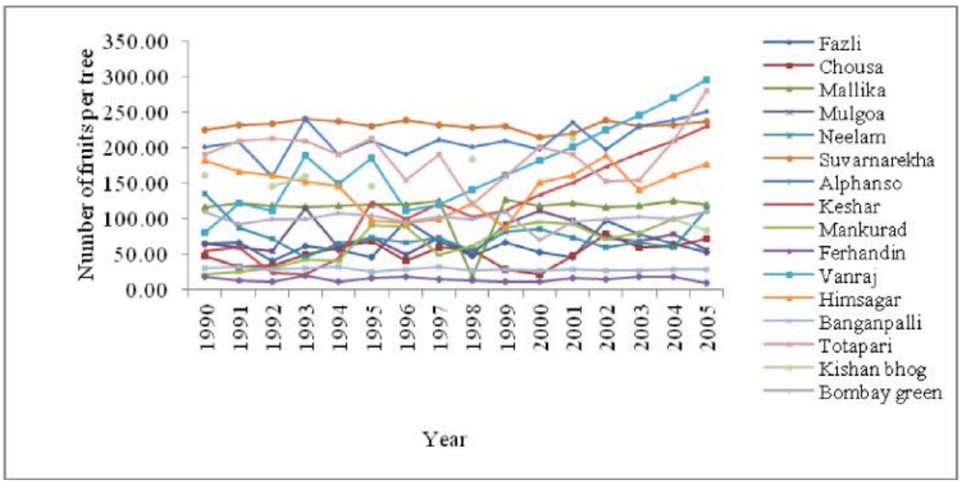


**Fig. 3. Number of fruits per tree from 1990 to 2005 at Vengurla centre for 16 varieties**

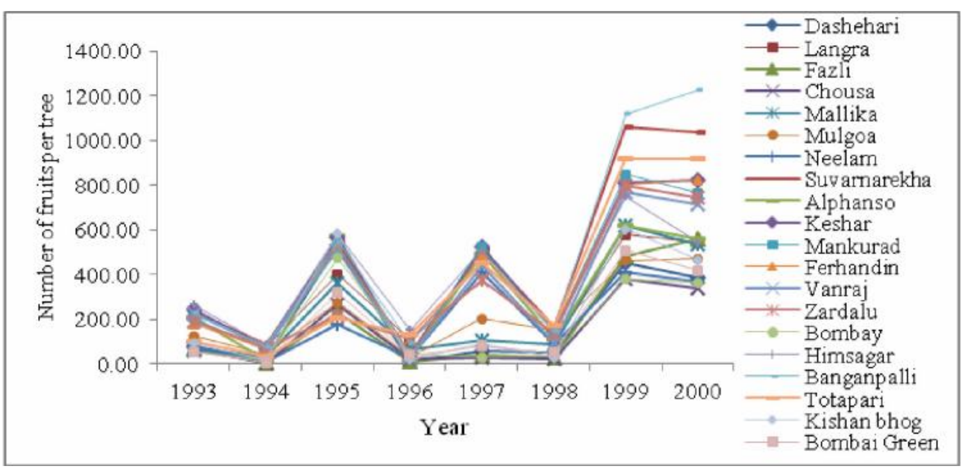


**Fig. 4. Number of fruits per tree from 1993 to 2000 at Sabour centre for 20 varieties**

been observed that range of percentage trees in 'on' phase is lowest at Vengurla followed by Sangareddy. The probable reason for variation in bienniality could be the influence of weather, which masks the actual bienniality. For example, in a particular year due to favourable weather, even the trees that are in 'off' phase may show a rise in yield and therefore a false 'on' phase may be presumed. Such false 'on' phase trees are shown in bold face in Table 1. At Rewa centre in years 2001 and 2003, at Sangareddy in years 1997 and 2001, at Vengurla in 2005 and at Sabour in1993, 1995 and 1997 years were in false 'on' phase. A similar reverse situation i.e., false 'off' phase can be observed when trees in 'on' phase are exposed to un-favourable years. The same were observed at Rewa centre in 1998 and 2002, at Sangareddy centre in 1998 and at Sabour in 1994, 1996 and 1998.

***'B' factor***

The proportion of mango trees showing varying degree of bienniality based on 'B' factor for centre-wise and for genotype-wise are presented in Table 2 and Table 4, respectively. The data for 112 trees at Rewa centre for 12 years, for 43 trees at Sangaready centre for 14 years, for 70 trees at Vengurla for 16 years and for 80 trees at Sabour for 8 years were analysed to estimate 'B' factor. For testing the significance of bienniality in mango based on equiprobable hypothesis, binomial probability was obtained

**Table 1.** Number of trees in 'on' phase, 'off' phase and percentage trees in 'on' phase at different centres

| Rewa | | | | Sangareddy | | | |
|---|---|---|---|---|---|---|---|
| Year | 'On' phase | 'Off' phase | % 'On' phase | Year | 'On' phase | 'Off' phase | % 'On' phase |
| 1997 | 69 | 43 | 61.61 | 1992 | 29 | 14 | 67.4 |
| 1998 | 8 | 104 | 7.14 | 1993 | 14 | 29 | 32.6 |
| 1999 | 62 | 50 | 55.36 | 1994 | 30 | 13 | 69.8 |
| 2000 | 32 | 80 | 28.57 | 1995 | 12 | 31 | 27.9 |
| 2001 | 102 | 10 | 91.07 | 1996 | 24 | 19 | 55.8 |
| 2002 | 4 | 108 | 3.57 | 1997 | 31 | 12 | 72.1 |
| 2003 | 107 | 5 | 95.54 | 1998 | 11 | 32 | 25.6 |
| 2004 | 23 | 89 | 20.54 | 1999 | 29 | 14 | 67.4 |
| 2005 | 62 | 50 | 55.36 | 2000 | 15 | 28 | 34.9 |
| 2006 | 61 | 51 | 54.46 | 2001 | 34 | 9 | 79.1 |
| 2007 | 37 | 75 | 33.04 | 2002 | 12 | 31 | 27.9 |
| 2008 | 75 | 37 | 66.96 | 2003 | 12 | 31 | 27.9 |
| | | | | 2004 | 21 | 22 | 48.8 |
| | | | | 2005 | 22 | 21 | 51.2 |
| Vengurla | | | | Sabour | | | |
| 1990 | 32 | 38 | 45.71 | 1993 | 80 | 0 | 100 |
| 1991 | 39 | 31 | 55.71 | 1994 | 0 | 80 | 0 |
| 1992 | 27 | 43 | 38.57 | 1995 | 80 | 0 | 100 |
| 1993 | 37 | 33 | 52.86 | 1996 | 4 | 76 | 5 |
| 1994 | 29 | 41 | 41.43 | 1997 | 73 | 7 | 91.25 |
| 1995 | 43 | 27 | 61.43 | 1998 | 0 | 80 | 0 |
| 1996 | 27 | 43 | 38.57 | 1999 | 65 | 15 | 81.25 |
| 1997 | 38 | 32 | 54.29 | 2000 | 15 | 65 | 18.75 |
| 1998 | 21 | 49 | 30.00 | | | | |
| 1999 | 27 | 43 | 38.57 | | | | |
| 2000 | 29 | 41 | 41.43 | | | | |
| 2001 | 35 | 35 | 50.00 | | | | |
| 2002 | 27 | 43 | 38.57 | | | | |
| 2003 | 19 | 51 | 27.14 | | | | |
| 2004 | 21 | 49 | 30.00 | | | | |
| 2005 | 48 | 22 | 68.57 | | | | |

for all the centres and presented in Table 2. It has been found that significant departure from equiprobable hypothesis was observed. Thus, a mango tree showing 'B' factor higher than 8/10, 9/12, 10/14 and 5/6 for Rewa, Sangareddy, Vengulra and Sabour respectively is considered to be significantly biennial in bearing (Table 2). The cumulative percentage trees exhibiting significant biennial bearing in Rewa, Sangaready, Vengurla and Sabour were 50.89, 41.86, 30 and 91.30% respectively at 5 % level of significance (Table 2).

### *'I' factor*

Distribution and percentage of trees in different ranges of "percentage of average 'I' factor" (PAIF) are given in Table 3 and genotype-wise distribution is presented in Table 4. It can be observed from Table 3 and Table 4 that the PAIF shows significant bienniality for all the cultivars in all the considered centres. It can be observed that percentage trees varied 0 to 100.0 from centre to centre in the range of 40 to 50 PAIF (Table 3). Further, it is confirmed that 46.5% trees at Rewa, 53.4% at Sangareddy and 100% at Sabour are showing PAIF greater than 40. The variety-wise intensity of bienniality ranges from 18.28 (Mankurad) to 64.24 (Chousa) at Rewa, 40.42 (Mallika) to 72.02 (Alphanso) at Sabour, 8.00 (Kishan bhog) to 100 (Mankurad, Ferhandin, Zardalu Mombay, Kishan bhog and Bombay green) at Sangareddy and from 0.80 (Mallika) to 19.25 (Mankurad) at Vengurla (Table 4). The average intensity along with standard error of bienniality in Sabour was found to be 56.61 (±0.88) as highest followed by Sangareddy 43.46 (±1.61), Rewa 39.76 (±0.92) and lowest at Vengurla 9.25 (±0.53). Previous study conducted by Reddy et al. (2003) in mango showed that the 'B' factor ranges from 41.7 to 75.0 and 'I' factor from 26 to 38 for different root stocks of Alphanso. The percentage of mean value of 'I' factor ranges from 45 to70% in case of apple (Preston 1956) and 10 to 20% in case of palm tree (Abeywardena 1962), 0.04 to 83% in Pistachio (Rosenstock 2010) and 55-75% in case of orange (Wahi and Malhotra 1993). This clearly indicates that the results obtained in the present study are in line with the previous results obtained.

The co-efficient of variation (CV) for the 'B' factor and PAIF were computed for different genotypes and results are presented in Table 4. On the basis of CV, Mallika with 6.73 is found to be most consistent in term of bienniality over locations followed by

**Table 2.** 'B' factor indicating significant bienniality at different centres

| Centre | Total no. of tree | 'B' factor | No. of trees in bienniality | % B trees | Percentage trees | c. f. of percentage trees | P(x) | Cumulative probability |
|---|---|---|---|---|---|---|---|---|
| Rewa | 112 | 8/10 | 29 | 80.00 | 25.89 | 50.89 | 0.0439 | 0.055 |
| Sangareddy | 43 | 9/12 | 8 | 75.00 | 18.60 | 41.86 | 0.0537 | 0.073 |
| Vengurla | 70 | 10/14 | 7 | 71.43 | 10.00 | 30.00 | 0.0611 | 0.089 |
| Sabour | 80 | 5/6 | 14 | 71.43 | 17.50 | 91.30 | 0.0940 | 0.109 |

c.f. = Cumulative frequency, P(x) = Probability at given number of pair

**Table 3.** Frequency distribution of percentage 'I' factor at different centres

| | Rewa | | | Sabour | | | Sangareddy | | | Vengurla | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| % 'I' factor | No. of trees | % trees | Cumu-lative trees | No. of trees | % trees | Cumu-lative trees | No. of trees | % trees | Cumu-lative trees | No. of trees | % trees | Cumu-lative trees |
| 0-10 | 0 | 0 | | 0 | 0 | | 0 | 0 | | 42 | 60 | 100 |
| 10-20 | 1 | 0.89 | 100.0 | 0 | 0 | | 0 | 0 | | 28 | 40 | 40 |
| 20-30 | 19 | 17.0 | 99.2 | 0 | 0 | | 4 | 9.3 | 100.0 | 0 | 0 | 0 |
| 30-40 | 40 | 35.7 | 82.2 | 0 | 0 | | 16 | 37.2 | 90.7 | 0 | 0 | 0 |
| 40-50 | 33 | 29.46 | 46.5 | 16 | 20 | 100 | 11 | 25.6 | 53.4 | 0 | 0 | 0 |
| 50-60 | 18 | 16.1 | 17.0 | 31 | 38.8 | 80 | 9 | 20.9 | 27.8 | 0 | 0 | 0 |
| 60-70 | 1 | 0.89 | 0.9 | 29 | 36.2 | 41.2 | 3 | 7.0 | 7.0 | 0 | 0 | 0 |
| 70-80 | | | | 4 | 5 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 112 | 100 | | 80 | 100 | | 43 | 100 | | 70 | 100 | |

Deshehari with 11.30, Kishan bhog with 11.81. It is worth noted that Vanraj is the least consistent genotype with highest CV 50.02. As far as intensity 'I' factor is concerned, Chousa is highly consistent with CV 9.08 followed by Alphanso with CV 17.6. Whereas, Suvarnrekha was observed to be least consistent with CV 71.67 in terms of intensity of bienniality over centres. Overall, the value of 'B' factor varies from 28.57 to 100 % and PAIF varies from 0.80 to 100 %. Highest extent of bienniality was exhibited by Bombay variety with 100% 'B' factor at Rewa, Keshar variety at Sangaready and all the genotypes at Sabour centre except Mallika, Fazli, Keshar, Bombay and Banganpalli variety. None of the varieties exhibits 100 % bienniality at Vengurla centre. Suvarnrekha at Rewa; Fazli at Sabour; Mankurad, Vanraj, Ferhandin, Bombay and Himsagar at Sangaready were observed with 50% 'B' factor and Vanraj at Vengurla with 'B' factor 28.57 exhibits lowest bienniality (Table 4).

***Auto-correlation***

The test of independence of error has been carried out after fitting the model for two cases (i) data with bienniality and (ii) data after eliminating the bienniality by taking moving average over two consecutive years. Box-Ljung test statistic has been used to test null hypothesis of no auto-correlation in errors with lag one. In presence of bienniality the auto-correlation between errors was found to be 0.024 with standard deviation 0.021. The value of Box-Ljung statistic was 1.37 with p-value 0.0242 *i.e.* non-significant at 1% level of significance. That is, errors are independent at lag one in case of original data with bienniality. However, when bienniality is eliminated by taking moving average of every two consecutive years, the value of auto-correlation was observed as 0.55 with standard error 0.022. The value of test statistic is 616.24 with p-value less than 0.0001. Hence, it is interpreted that errors became auto-correlated at lag one when bienniality was eliminated by taking moving average. The genotype-wise computed errors have shown the same trend of auto-correlation (near 0.5) when bienniality was removed whereas they were independent in case of original data. The auto-

**Table 4.** Percentage trees corresponding %‘ B’ factor and minimum and maximum values of % average ‘I’ factor along with CV for all varieties tested at different centres

| Centre | Rewa | | | | Sangareddy | | | | Vengurla | | | | Sabour | | | | CV over centres | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variety | ‘B’ fact. | | % av. ‘I’ fact. | | ‘B’ fact. | | % av. ‘I’ fact. | | ‘B’ fact. | | % av. ‘I’ fact. | | ‘B’ fact. | | % av. ‘I’ fact. | | | |
| | % ‘ B’ fact. | % tree | Min | Max | % ‘ B’ fact. | % tree | Min | Max | % ‘ B’ fact. | % tree | Min | Max | % ‘ B’ fact. | % tree | Min | Max | CV of % ‘ B’ fact. | CV of % av. ‘I’ fact. |
| Dashehari | 80.00 | 50.00 | 35.60 | 45.82 | 87.71 | 35.50 | 83.00 | 97.00 | —- | —- | —- | —- | 100.00 | 100.00 | 52.97 | 58.13 | 11.30 | 39.88 |
| Langra | 90.00 | 87.50 | 44.35 | 57.42 | 71.43 | 50.00 | 71.00 | 92.00 | —- | —- | —- | —- | 100.00 | 100.00 | 53.83 | 59.59 | 16.64 | 27.80 |
| Fazli | 80.00 | 7.50 | 35.90 | 49.60 | 78.57 | 25.00 | 62.00 | 86.00 | —- | —- | —- | —- | 50.00 | 75.00 | 60.22 | 61.86 | 24.34 | 28.14 |
| Chousa | 90.00 | 100.00 | 42.50 | 64.24 | 57.14 | 37.50 | 37.47 | 76.21 | —- | —- | —- | —- | 100.00 | 100.00 | 54.11 | 66.94 | 27.22 | 9.08 |
| Mallika | 70.00 | 62.50 | 20.40 | 36.98 | 75.00 | 50.00 | 43.00 | 77.00 | 64.29 | 67.00 | 0.80 | 11.26 | 66.67 | 50.00 | 40.42 | 42.80 | 6.73 | 64.40 |
| Mulgoa | —- | —- | —- | —- | 78.57 | 25.00 | 52.00 | 88.00 | 71.43 | 75.00 | 15.53 | 16.99 | 100.00 | 75.00 | 48.69 | 52.99 | 17.84 | 67.43 |
| Neelam | 80.00 | 87.50 | 36.83 | 44.52 | 78.57 | 25.00 | 44.00 | 86.00 | 78.57 | 25.00 | 9.07 | 15.45 | 100.00 | 100.00 | 64.17 | 67.40 | 12.46 | 57.04 |
| Suvarnarekha | 50.00 | 37.50 | 19.38 | 39.38 | 71.43 | 50.00 | 42.00 | 61.00 | 64.29 | 50.00 | 0.00 | 0.00 | 100.00 | 100.00 | 58.80 | 63.23 | 29.44 | 71.67 |
| Alphanso | —- | —- | —- | —- | 75.00 | 50.00 | 10.78 | 92.50 | —- | —- | —- | —- | 100.00 | 100.00 | 70.51 | 72.02 | 20.20 | 17.61 |
| Keshar | —- | —- | —- | —- | 100.00 | 37.50 | 18.03 | 94.18 | 50.00 | 25.00 | 5.90 | 13.51 | 83.33 | 75.00 | 62.03 | 64.77 | 32.73 | 71.02 |
| Mankurad | 70.00 | 50.00 | 18.26 | 48.90 | 50.00 | 75.00 | 37.00 | 100.00 | 64.29 | 37.50 | 4.34 | 19.25 | 100.00 | 75.00 | 51.23 | 62.90 | 29.60 | 58.04 |
| Ferhandin | —- | —- | —- | —- | 50.00 | 62.50 | 52.00 | 94.00 | 64.29 | 25.00 | 13.03 | 18.16 | 100.00 | 75.00 | 58.72 | 60.67 | 36.05 | 65.98 |
| Vanraj | 90.00 | 50.00 | 21.83 | 48.25 | 50.00 | 37.50 | 55.00 | 100.00 | 28.57 | 50.00 | 0.00 | 0.00 | 100.00 | 100.00 | 61.44 | 63.75 | 50.02 | 78.22 |
| Zardalu | 50.00 | 50.00 | 30.11 | 40.85 | 75.00 | 50.00 | 61.00 | 82.00 | —- | —- | —- | —- | 100.00 | 100.00 | 42.99 | 45.18 | 33.33 | 40.37 |
| Bombay | 100.00 | 50.00 | 39.76 | 58.10 | 50.00 | 50.00 | 60.00 | 100.00 | —- | —- | —- | —- | 66.67 | 50.00 | 46.28 | 55.43 | 35.25 | 35.12 |
| Himsagar | —- | —- | —- | —- | 50.00 | 62.50 | 48.00 | 100.00 | —- | —- | —- | —- | 100.00 | 100.00 | 53.09 | 53.78 | 47.14 | 42.50 |
| Banganpalli | 60.00 | 50.00 | 33.98 | 50.32 | 71.57 | 37.50 | 54.00 | 74.00 | 71.43 | 33.33 | 4.79 | 8.16 | 83.33 | 100.00 | 56.25 | 58.34 | 13.31 | 58.98 |
| Totapari | 70.00 | 87.50 | 22.30 | 31.53 | 78.57 | 50.00 | 35.00 | 74.00 | 57.14 | 75.00 | 6.61 | 8.94 | 100.00 | 75.00 | 41.73 | 44.50 | 23.57 | 68.33 |
| Kishan bhog | 90.00 | 62.50 | 46.10 | 62.96 | 75.00 | 62.50 | 8.00 | 100.00 | 85.71 | 50.00 | 4.86 | 7.16 | 100.00 | 50.00 | 48.18 | 66.36 | 11.81 | 65.06 |
| Bombay Green | —- | —- | —- | —- | 75.00 | 62.50 | 86.00 | 100.00 | —- | —- | —- | —- | 100.00 | 50.00 | 53.17 | 57.66 | 20.20 | 37.98 |

av. = Average; fact. = Factor

correlation approximately of 0.5 may be due to the fact that one year remains common between any two pairs of consecutive years.

***Estimation of repeatability***

Repeatability was estimated for number of fruits per tree using ANOVA estimators after applying square root $\left(\sqrt{x-0.5}\right)$ and logarithmic $Log(x-0.5)$ transformations by MA-I and MA-II. These transformations were done to see their effects on the estimates of repeatability. The different estimates of repeatability along with their standard errors are presented in Table 5. It is evident that the estimate of repeatability (rho) was lowest at Sabour centre whereas moderate to high estimates of repeatability were observed at most of the centres. The use of square root and logarithmic transformations lead to slight increase in the estimates of repeatability over ANOVA except in Sangareddy. This indicates that negative bias in the ANOVA estimate due to presence of biennial rhythm in the data has reduced to some extent by the transformation. The negative bias in the ANOVA estimate of repeatability was eliminated in most of the centres by taking moving average except at Vengurla.

significance. As far as intensity of bienniality is concerned, 46.5 % trees at Rewa, 100% at Sabour, and 53.4% at Sangareddy showed greater than 40% average 'I' factor. It is also concluded that Millika variety exhibits most consistent bienniality over different centres followed by Dashehari and Kishan bhog. The consistency in bienniality was lowest in Vanraj variety. Moreover, Suvarnrekha variety at Rewa, Fazli at Sabour, Mankurad, Vanraj, Ferhandin, Bombay and Himsagar at Sangareddy have exhibited high bienniality whereas Vanraj at Vengurla showed lowest bienniality.

Further, a significant auto-correlation 0.5 with lag one in the errors after eliminating bienniality by taking moving average of two consecutive years was observed whereas no auto-correlation was observed in the original data. The repeatability estimates were underestimated by ANOVA method due to presence of bienniality. However, the negative bias in the ANOVA estimates has been reduced by using MA-I and MA-II at all the centres except Vengurla. The trait "*number of fruits per tree*" was found to be moderate to highly repeatable.

**Table 5.** Estimated repeatability and standard error by ANOVA, MA-I and MA-II

| Centre | Methods | rho | S.E. | Centre | Methods | rho | S.E. |
|---|---|---|---|---|---|---|---|
| Rewa | ANOVA | 0.224 | 0.031 | Sabour | ANOVA | 0.013 | 0.023 |
| | ANOVA* | 0.287 | 0.085 | | ANOVA* | 0.016 | 0.023 |
| | ANOVA** | 0.285 | 0.085 | | ANOVA** | 0.038 | 0.026 |
| | MA-I | 0.264 | 0.034 | | MA-I | 0.040 | 0.029 |
| | MA-II | 0.239 | 0.032 | | MA-II | 0.031 | 0.009 |
| Sangareddy | ANOVA | 0.287 | 0.059 | Vengurla | ANOVA | 0.799 | 0.081 |
| | ANOVA* | 0.275 | 0.054 | | ANOVA* | 0.831 | 0.071 |
| | ANOVA** | 0.184 | 0.045 | | ANOVA** | 0.858 | 0.061 |
| | MA-I | 0.366 | 0.060 | | MA-I | 0.709 | 0.037 |
| | MA-II | 0.350 | 0.057 | | MA-II | 0.705 | 0.037 |

Note: *and** represent $\left(\sqrt{x-0.5}\right)$ and log ($x$ + 0.5) respectively

The present study confirmed the biennial bearing tendency in mango for the trait "*number of fruits per tree*". The graphical and numerical measures of bienniality indicated the extent and intensity of bienniality in mango. Based on 'B' factor 50.89% trees at Rewa, 41.86 % at Sangareddy, 30% at Vengulra and 91.3 % trees at Sabour centres were exhibiting significant bienniality in bearing at 5% level of

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