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# SELECTION OF LATE BLIGHT RESISTANT VARIETIES IN BANGLADESH FROM CIP POPULATION B3 POTATO CLONES

Abdullah-Al-Mahmud<sup>1\*</sup>, Merideth Bonierbale<sup>2</sup>, Mohinder Singh Kadian<sup>3</sup>, Mohammad Hossain<sup>4</sup>, Bimal Chandra Kundu<sup>5</sup>, E.H.M. Shofiur Rahaman<sup>6</sup>, Md. Jahangir Alam<sup>1</sup>, Mohidul Hasan<sup>7</sup>, Md. Matiar Rahman<sup>5</sup>, Md. Abu Kawochar<sup>5</sup> and Md. Nizam Uddin<sup>5</sup>

**ABSTRACT:** Bangladesh is in a subtropical monsoon region and extends from 20°34'N to 26°38'N latitude, its agriculture is comprised of several diversified rice-based cropping systems. Potato is an important winter crop across the country. To help increase the sustainability of potato production in Bangladesh, a set of medium-term late blight-resistant potato clones bred in CIP were evaluated for diversification potential at six locations from 2008 to 2013. After seven years of field trials, TCRC, BARI identified two clones, namely CIP 393371.58 (coded LB-6) and CIP 393280.64 (LB-7) which are consistently resistant to Late Blight under field conditions without fungicide and yield as well or better than the predominant commercial varieties (Diamant) in a 90-day cropping window. According to the AUDPC, LB-4, LB-5, LB-6 and LB-7 were moderate to highly resistant to Late Blight. The latter two produced over 30 tons of tubers per hectare. Similar yields were recorded in on-farm trials during 2011-12. These two clones were entered into regional yield trials as a requirement for variety release by the NSB. Based on field performance at on-station and farmers' fields, NSB released BARI Alu-46 (LB-7) in 2013 and BARI Alu-53 (LB-6) in 2014 as the country's two late blight-resistant varieties.

**KEYWORDS:** Potato; late blight resistance; earliness

## ABBREVIATIONS:

LB: Late blight  
CIP: International Potato Center  
TCRC: Tuber Crops Research Centre  
BARI: Bangladesh Agricultural Research Institute  
AEZ: Agro-Ecological Zone  
NSB: National Seed Board  
AUDPC: Area under the disease progress curve  
PYT: Preliminary Yield Trial  
SYT: Secondary Yield Trial  
AYT: Advanced Yield Trial  
RYT: Regional Yield Trial  
DUS: Distinctness, Uniformity, and Stability

## INTRODUCTION

Bangladesh's agriculture is predominantly based on smallholdings with about 80% of the farmers cultivating less than one hectare, Land preparation is transitioning from the use of draft animals and hand tools to the use of small machinery such as power tillers. Intensive cropping patterns help to satisfy the increasing food and other demands of the country's rising population on agriculture, and innovations take cropping patterns into account. The improvement of varieties for intensive cropping patterns requires a combined approach of early-stage selection for disease resistance, adaptation to

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temperature, photoperiod, soil, and related factors as for monoculture, followed by validation trials under farm conditions for measuring yield potential under multiple stresses, and eventually evaluating total system performance (Francis and Smith, 1985).

As an increasingly important part of several diverse and complex cropping systems, potato (*Solanum tuberosum* L.) is the third most important food crop in Bangladesh, after paddy rice and wheat. It is an increasingly successful cash crop, with unit yield and gross return higher than other winter crops and second only to that of paddy rice. (<https://www.potatopro.com/bangladesh/potato-statistics>). Bangladesh ranks 8th in world potato production and 3rd in Asia (FAOSTAT, 2018). Over the past two decades, the country's potato production grew from 1.55 Mt to 9.47 Mt, on the area that expanded from 0.136 to 0.47 M ha.; with recent yields ranging from 18.1 to 20.41 t/ha (FAOSTAT, 2018). The country needs 0.76 Mt of seed potatoes for total potato production, whereas government organizations can supply only 5% quality seed potatoes (BADC, 2022).

The lack of short-season disease-resistant potato varieties, lack of timely seed supply and inefficient market systems persist as major constraints to enhancing productivity and profitability of the crop (Kadian *et al.*, 2009; Singha and Maezawa, 2019). Despite concerted national and international research and development efforts to improve potato production, the crop is challenged by edaphic-climatic adversities (drought, heat, and salinity) and by diseases caused by viral, bacterial, and fungus-like pathogens such as the causal agent of potato late blight.

Late blight (LB), caused by the Oomycete *Phytophthora infestans*, occurs regularly in

the Indo-Gangetic Plains of Bangladesh and West Bengal, India) where it causes yield loss ranging from 25 to 60% (Khan *et al.*, 1989; Ali and Dey, 1998). Severity depends upon the susceptibility of the variety, the aggressiveness of local pathogen populations, the effectiveness of complementary control methods and the prevailing environmental factors (Dey *et al.*, 1995; Hossain *et al.*, 2002). Deployment of resistant varieties is the best option against late blight, but in the absence of these, Bangladeshi farmers apply upward of 7-8 sprays per season at the cost of about 13500-15000 Tk./ha or 5-6% of the total production cost (Haque *et al.*, 2012). *P. infestans* has displayed large flexibility in its adjustment to a changing environment. The appearance of new populations and races of *P. infestans* has been associated with the breakdown of resistance. This necessitates the search for resources with effective resistance to predominant forms of the pathogen; In tandem with the characterization of the pathogen, the evaluation of germplasm for resistance to Late Blight has turned out to be a regular activity worldwide (Kaushik *et al.*, 2007; Wulff *et al.*, 2007). One way to identify durable resistance in potato genotypes is to assess them in time (two or more seasons testing at a location) or spatially (in several locations and in large plots) or a combination of these (Cotes *et al.*, 2002).

Toward the development of medium maturing, late blight resistant cultivars, the Tuber Crops Research Centre (TCRC) introduced advanced bred lines from the International Potato Center (CIP) in Peru in 2008 and these were evaluated for seven years following standard evaluation procedures (Rashid *et al.*, 1987; BARI 2009; BARI 2015; Kundu *et al.*, 2013; Kundu *et al.*, 2018). Here, we report on the advanced stages of clonal evaluation to identify suitable short-season, late blight-resistant potato varieties for rice-

based systems of Bangladesh and validate farmers' and consumers' acceptance and the on-farm performance of two recently released varieties.

## MATERIALS AND METHODS

### Plant Material

A set of 12 advanced potato clones bred by CIP were evaluated at Bogura, Munshiganj, and Jamalpur during 2008-09, 2009-10, and 2010-11 under a collaborative project supported by GTZ, Germany (Table 1).

All test clones were from recurrent selection cycles 1 or 2 (C1 or C2) of CIP's Population B3 bred in Peru for table quality, yield and disease resistance (Lindqvist-Kreuze

*et al.*, 2014). Each selection cycle consisted of evaluation over 4 years in 4 subtropical lowland and tropical highland environments with and without exposure to high levels of endemic pressure from late blight. They were further assessed for resistance to three virus diseases by intentional exposure to PLRV, PVX and PVY. The clones were transferred to Bangladesh as in vitro plantlets under the terms of a Material Transfer Agreement ([https://research.cip.cgiar.org/cipcatlg\\_ac/Catalogue.php?](https://research.cip.cgiar.org/cipcatlg_ac/Catalogue.php?)). Upon introduction to Bangladesh through TCRC, the plantlets were acclimated to screen house conditions and grown out to produce tuber seed. Hereafter, the term  $F_1$  is used to denote the clones' hybrid constitution and the terms  $C_1$ ,  $C_2$ ,  $C_3$ ,

Table 1. Key characters of potato clones used in the variety testing program during 2008-2013

| CIP No.        | TCRC code | Key characters                                                                                                                                                    | Population cycle | Resistance traits                             |
|----------------|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|-----------------------------------------------|
| CIP 391004.18  | LB 1      | White-Cream skin, Pale yellow tuber flesh color, Long-oblong tuber shape, shallow eye depth                                                                       | B3C1             | Late Blight                                   |
| CIP 391046.14  | LB 2      | White cream skin, yellow flesh color, oblong shape with shallow eye depth.                                                                                        | B3C1             | Late Blight, PVX (ER) and PVY (ER)            |
| CIP 391058.175 | LB 3      | White cream skin, yellow flesh color, oblong-flattened tuber shape with shallow eye depth.                                                                        | B3C1             | Late Blight                                   |
| CIP 393077.159 | LB 4      | White cream skin, cream flesh color, oblong- tuber shape with shallow eye depth.                                                                                  | B3C1             | Late Blight and PVX (ER)                      |
| CIP 393085.5   | LB 5      | White cream skin, cream flesh color, oblong- tuber shape with shallow eye depth.                                                                                  | B3C1             | Late Blight, PVX (ER) and PVY (ER)            |
| CIP 393280.64  | LB 6      | Red skin, oblong tuber shape and pale-yellow flesh with superficial eyes, medium to large tuber sizes, high tuber number per plant with wide range of adaptation. | B3C1             | Late Blight PVX and PLRV                      |
| CIP 393371.58  | LB 7      | Crème skin color with pink eyes, oblong tuber shape, cream flesh with superficial eyes, medium to large tuber sizes, High yield under LB disease.                 | B3C1             | late blight and PVX (ER)                      |
| CIP 395011.2   | LB 8      | White cream skin, cream flesh color, oblong- tuber shape with shallow eye depth.                                                                                  | B3C2             | Resistant to Late Blight PVX (ER) and PVY(ER) |
| CIP 396004.337 | LB 9      | White cream skin, cream flesh color, oblong- tuber shape with shallow eye depth.                                                                                  | B3C2             | Resistant to Late Blight                      |
| CIP 396031.108 | LB 11     | White cream skin, cream flesh color, oblong- tuber shape with shallow eye depth.                                                                                  | B3C2             | Resistant to Late Blight                      |
| CIP 396031.119 | LB 12     | Pink skin, pale yellow flesh color, oblong- tuber shape with shallow eye depth.                                                                                   | B3C2             | Resistant to Late Blight                      |
| CIP 396031.119 | LB 14     | White cream skin, cream flesh color, oblong- tuber shape with shallow eye depth.                                                                                  | B3C2             | Resistant to Late Blight                      |

ER- extreme resistance (After: Catalogue of Advanced Clones (cgiar.org), ([https://research.cip.cgiar.org/cipcatlg\\_ac/Catalogue.php?](https://research.cip.cgiar.org/cipcatlg_ac/Catalogue.php?)))

etc. refer to cycles of clonal propagation for successive evaluation trials after recovery from in vitro conditions. Selections were carried out based on foliage type, tuber yield, tuber qualities and LB infection.

## Field Trials (2008-2013)

### Trial Management

A series of on-station and on-farm trials were conducted in 6 agro-ecological zones (AEZ) of Bangladesh to evaluate 12 advanced bred clones from CIP and validate the acceptance and performance of two that were recommended and released as varieties. The series of activities conducted for potato variety testing, release, and recommendation by BARI is illustrated in Figure 1.

All field trials ranging from preliminary, secondary, advanced, and regional yield trials (PYT, SYT, AYT and RYT) were conducted on research stations of TCRC in 3m × 3m plots. The on-station trials in each location

were replicated thrice with a row spacing of 60 cm and plant spacing of 25 cm, The  $F_1C_1$  and  $F_1C_2$  clonal generations were evaluated in PYT and SYT, respectively, at three trial sites, namely, Jamalpur, Bogura, and Munshiganj. Clones in  $F_1C_3$  and  $F_1C_4$  were evaluated under AYT in 4 trial sites and RYT at six trial sites namely, Rangpur (AEZ 2), Bogura (AEZ 4), Jamalpur (AEZ 8), Jashore (AEZ 11) Munshiganj (AEZ 16) and Joydebpur (AEZ 28) (FRG, 2018). Additionally, in 2011-12, farmers' field trials were conducted in Bogura (3) Jamalpur (3) and Cumilla (3) to validate and compare the on-station yield of the two most promising clones with the yield in farmer's field conditions. In RYT, plots were harvested at 2 stages, at 65 days to measure the earliness of tuber bulking and at 90 days. Varietal performance was validated through on-farm, adaptive trials after the release of two of the clones as new varieties. This validation was performed across 250 trials at 12 locations under the Potato-Rice-

The scheme of potato variety evaluation/development protocol is presented in Fig. 1.

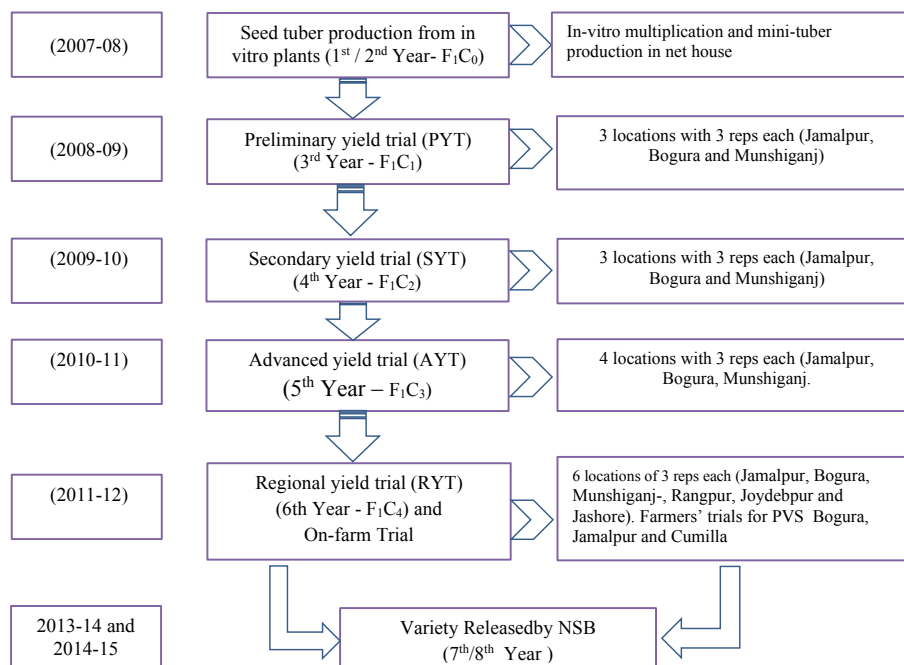


Fig. 1 Activities followed in LB resistant potato Variety Development by TCRC, Bangladesh

Rice system during 2015-16. Disease-free seed tubers were supplied to the farmers, who were then responsible for all aspects of management. The potato plots were harvested at 90 DAP with the attendance of scientists and farmers. Participatory assessment of farmer's preferences was conducted through consultation on Late blight resistance, plant appearance, marketability and overall acceptability.

In RYT, data were collected on morphological and tuber characteristics, yield at 65 and 90 DAP (t/ha), tuber dry matter (%) and post-harvest behavior in ambient conditions were compiled and submitted to National Seed Board (NSB) to recommend the top-performing two clones for variety release.

### Agronomic management

Properly sprouted un-cut seed potatoes were sown on 15 November and 20 December each year, at 1500 kg/ha. Before planting, seed tubers of each genotype were treated with carbendazim (0.1%). Crops were fertilized according to the fertilizer recommendation guide (FRG, 2018). The crops were irrigated four times. Light irrigation was applied at 8–10 DAP for proper emergence of the tubers; the 2nd and 3rd irrigations were applied at 30–35 and 45–50 DAP reaching 2/3rd of the furrow depth. Finally, after 60–65 DAP, light irrigation was also applied. Two hands weeding were done before the 2nd (at 30–35 DAP) and 3rd (60–65 DAP) irrigations. Carbofuran (Furadan 5G®, Padma Oil Company Limited, Bangladesh) was applied @ 500 g a.i./ha during land preparation to control cutworms and Imidacloprid (Admire 20 SL®, Bayer Crop Science Limited, Bangladesh) was sprayed @ 25 g a.i./ha at 45 and 60 DAP to control aphid vectors of potato viruses. No fungicides were applied to protect the test clones from late blight. Crops

were dehaulmed at 80 DAP and harvested after 10 days' curing (90 DAP.)

### Assessment of Quality Parameters

#### *Tuber dry matter:*

Dry matter (DM) estimation was performed from five randomly collected tubers of the 90-day harvest per plot in the RYT trials using fraction samples of 150 g fresh weight (dried in an oven for 72 hours at 80 °C until a constant weight was attained) (Gupta *et al.*, 2015). Final DM content was estimated by the following formula:

$$\text{Tuber dry matter (\%)} = \frac{\text{Sample dry weight} \times 100}{\text{Sample fresh weight}}$$

**Keeping quality:** Thirty tubers (ten each of large, medium and small size) of each genotype were stored in net boxes at ambient temperature. Weight loss and rottage were recorded at 15-day intervals up to 90 days after harvest.

### Measurement of Late Blight susceptibility

The percent of leaf area affected by *Phytophthora infestans* was recorded on a plot basis at 7-day intervals and averaged across reps before being used to calculate AUDPC according to the formula of Campbell and Madden (1990).

$$\text{AUDPC} = \sum_{i=1}^{n-1} \left( \frac{y_i + y_{i+1}}{2} \right) (t_{i+1} - t_i)$$

Where "t" is the time of each reading, "y" is the percentage of affected foliage at each reading and "n" is the number of readings. The AUDPC was calculated using Data Collector from CIP (<https://research.cip.cgiar.org/confluence/display/GDET4RT/Downloads>).

The clones were classified as highly resistant (AUDPC < 250), resistant (251-350), moderately resistant (351-650), susceptible

(65-1200) and highly susceptible (AUDPC >1200) when the susceptible control showed more than 90% late blight infection as per **Gopal and Singh (2003)**.

Virus disease incidence (PVY and PLRV) was determined by regular observation of the plants in the field trials, where the PVY and PLRV infected plants were recorded. The incidence of the two viruses was expressed in the percentage of plants with symptoms.

### Statistical Analysis

Total tuber yield (t/ha) (PYT, SYT and AYT) was used in a combined analysis of variance (ANOVA) to ascertain the contributions of genotype (G), environment (E) and their interaction (G×E) to the variation observed. Morphological and tuber parameters; yield at 65 and 90 DAP; tuber dry matter (%), keeping quality in ambient conditions were observed in RYT and the DUS test were recorded according to the format prescribed by the National Seed Board (NSB). Tuber yield was collected from an area of 3.6 m<sup>2</sup> (1.2 m × 3 m) in each of the locations and converted into t/ha. AUDPC data in successive generations (PYT, AYT and RYT) were also used in combined ANOVA to determine the contributions of genotype

(G), environment (E) and their interaction. Tuber yield (t/ha) data was collected from on-farm trials.

## RESULTS

### Climatic conditions of the trial sites

Meteorological data on minimum (night) and maximum (day) temperature (°C) during the potato growing seasons are presented in Fig. 2. Temperatures declined slightly from November to January and then increased gradually. The monthly average maximum temperature ranged from 23.4 to 36.0°C across the locations, with the lowest value in Rangpur (the northern part of Bangladesh) in January and the highest temperature in Munshiganj in March. Similarly, the monthly average minimum night temperature ranged from 10.7 to 23°C across the different trial sites, with the minimum in Rangpur in January and the maximum in Munshiganj in March.

### Tuber yield in successive generations (PYT, SYT, AYT and RYT) and in on-farm trials

Potato genotypes grown in different agro-ecological zones showed considerable variation in tuber yield (Table 3). Genotype (G), environment (E) and genotype × environment interaction (G × E) were highly

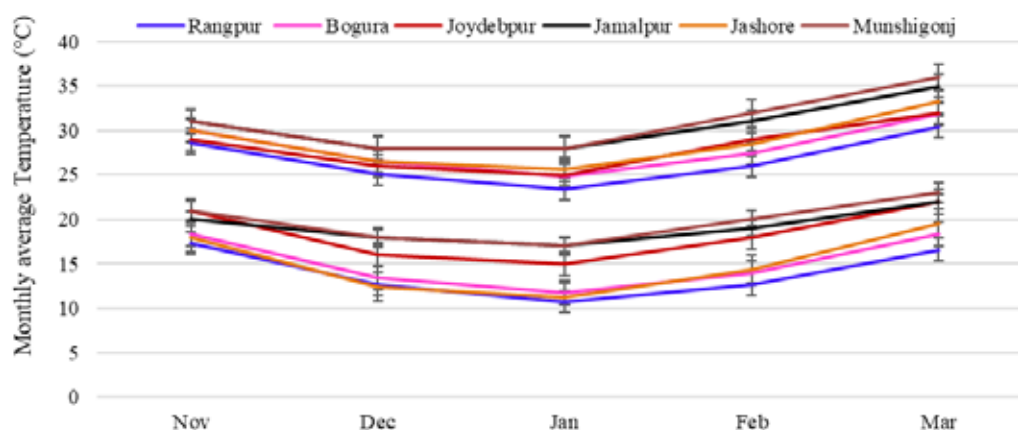


Fig. 2 Average air temperature °C (Max. and min.) in different trial sites during the crop growth period (2008-2012)

significant ( $p < 0.001$ ) (Table 2). The highly significant  $G \times E$  impacts suggest that potato genotypes may need to be cautiously chosen for an adjustment to specific environments.

In the PYT, selection considered the mean yield at 90 DAP across three locations, tuber shape, size, skin color, late blight resistance and overall appearance. Significant variation in yield was observed. The highest average yield was 27.00 t/ha for LB-7, closely followed by LB 8 (26.9 t/ha), LB-5 (24.70 t/ha), LB-4 (23.70 t/ha) and LB-6 (22.90 t/ha). The mean AUDPC for late blight in PYT was the highest

in Diamant, followed by LB-2, LB-1, LB-9 and LB-12. Considering AUDPC, only LB-5, LB-6, and LB-7 showed moderate resistance to the disease (Table 3). Considering all selection criteria, 7 clones were advanced to the secondary yield trial (SYT).

The SYT was conducted at 3 trial sites (Bogura, Jamalpur and Munshiganj) (Table 2). Significant variation in yield was observed. LB 7 produced the highest average yield (38.59 t/ha) at 90 DAP. The lowest yield was in LB-6, the average being 27.78 t/ha, whereas the check variety Diamant yielded

Table 2. Average total tuber yield at 90 DAP for genotypes and environments in PYT, SYT and AYT

| Factor                | Genotype              | Yield (t/ha) at 90 DAP |               |               |
|-----------------------|-----------------------|------------------------|---------------|---------------|
|                       |                       | PYT (2008-09)          | SYT (2009-10) | AYT (2010-11) |
| Genotypes             | LB 1 (CIP391004.18)   | 12.9 g                 | -             | -             |
|                       | LB 2 (CIP391046.14)   | 10.2 h                 | -             | -             |
|                       | LB 3 (CIP391058.175)  | 19.1 e                 | 32.55 bc      | 38.91 c       |
|                       | LB 4 (CIP393077.159)  | 23.7 c                 | 34.06 b       | -             |
|                       | LB 5 (CIP393085.5)    | 24.7 b                 | -             | -             |
|                       | LB 6 (CIP393280.64)   | 22.9 c                 | 27.78 d       | 41.16 b       |
|                       | LB 7 (CIP393371.58)   | 27.00 a                | 38.59 a       | 50.78 a       |
|                       | LB 8 (CIP395011.2)    | 26.90 a                | 34.36 b       | -             |
|                       | LB 9 (CIP396004.337)  | 15.3 f                 | -             | -             |
|                       | LB 11 (CIP396031.108) | 19.8 de                | -             | -             |
|                       | LB 12 (CIP396031.119) | 19.1 e                 | 33.56 b       | -             |
|                       | LB 14 (CIP396244.12)  | 21 d                   | 30.57 c       | -             |
|                       | Diamant               | 10.5 h                 | 31.55 c       | 36.28 d       |
| Environment           | Jamalpur              | 21.55 a                | 43.57 a       | 40.48 c       |
|                       | Bogura                | 12.36 b                | 25.02 c       | 41.87 b       |
|                       | Munshiganj            | 21.96 a                | 30.04 b       | 43.52 a       |
|                       | Rangpur               | -                      | -             | 41.25 b       |
|                       | Joydebpur             | -                      | -             | -             |
|                       | Jashore               | -                      | -             | -             |
| Level of Significance | Genotypes (G)         | **                     | **            | **            |
|                       | Environment (E)       | **                     | **            | **            |
|                       | $G \times E$          | **                     | **            | **            |
| CV (%)                |                       | 8.59                   | 5.27          | 5.27          |

\*\*Significant at 0.01 level of probability

31.55 t/ha. The second highest yielder was LB-8 (34.36 t/ha), followed by LB-4 (34.06 t/ha), LB-12 (33.56 t/ha) and LB-3 (32.55 t/ha). There was no late blight infection in any field during SYT due to unfavorable environmental conditions for disease development in 2009-10.

Considering tuber shape, size, color and yield, three clones (LB-3, LB-6 and LB-7) were selected for AYT. The AYT consisted of three clones and Diamant at four trial sites (Rangpur, Bogura, Jamalpur, and Munshiganj) (Table 2). Results revealed significant variation in tuber yield at all

locations. The outstanding performance was obtained in the clones LB-6 (41.16 t/ha) and LB-7 (50.78 t/ha) whereas the check variety Diamant produced 36.28 t/ha. Among the trial sites, mean tuber yield across the test clones varied from 40.48 to 43.52 t/ha. From mean AUDPC, disease in AYT was the highest in check Diamant followed by LB-3. Considering AUDPC, only LB-6 and LB-7 showed high and consistent resistance to Late Blight (Table 3).

Two clones - LB-6 and LB-7 were selected for evaluation in RYT at six locations, (Joydebpur, Jashore, Rangpur,

**Table 3. Average AUDPC for Late Blight of advanced CIP clones and check varieties in PYT, AYT and RYT at different experimental sites in Bangladesh**

| Factor                | Genotype              | AUDPC         |               |               |               |
|-----------------------|-----------------------|---------------|---------------|---------------|---------------|
|                       |                       | PYT (2008-09) | SYT (2009-10) | AYT (2010-11) | RYT (2011-12) |
| Genotypes             | LB 1 (CIP391004.18)   | 1983          | -             | -             | -             |
|                       | LB 2 (CIP391046.14)   | 2172          | -             | -             | -             |
|                       | LB 3 (CIP391058.175)  | 952           | -             | 212           | -             |
|                       | LB 4 (CIP393077.159)  | 743           | -             | -             | -             |
|                       | LB 5 (CIP393085.5)    | 614           | -             | -             | -             |
|                       | LB 6 (CIP393280.64)   | 587           | -             | 251           | 69            |
|                       | LB 7 (CIP393371.58)   | 486           | -             | 68            | 40            |
|                       | LB 8 (CIP395011.2)    | 686           | -             | -             | -             |
|                       | LB 9 (CIP396004.337)  | 1982          | -             | -             | -             |
|                       | LB 11 (CIP396031.108) | 631           | -             | -             | -             |
|                       | LB 12 (CIP396031.119) | 1775          | -             | -             | -             |
|                       | LB 14 (CIP396244.12)  | 992           | -             | -             | -             |
|                       | Diamant               | 2214          | -             | 716           | 939           |
| Environment           | Jamalpur              | 1917          | -             | 153           | 475           |
|                       | Bogura                | 1357          | -             | 519           | 782           |
|                       | Munshiganj            | 376           | -             | 47            | 1             |
|                       | Rangpur               | -             | -             | 526           | 839           |
|                       | Joydebpur             | -             | -             | -             | 1             |
|                       | Jashore               | -             | -             | -             | 1             |
| Level of Significance | Genotypes (G)         | **            | -             | **            | **            |
|                       | Environment (E)       | **            | -             | **            | **            |
|                       | G × E                 | **            | -             | **            | **            |
| CV (%)                |                       | 22.6          |               | 22.5          | 37.5          |

\*\*Significant at 0.01 level of probability

Bogura, Jamalpur and Munshiganj) along with two standard varieties as required for recommendation for release as commercial varieties (Table 4, 5). Plants of all tested clones including LB-6 and LB-7 were taller compared to their corresponding check varieties Cardinal and Diamant. At the same time, LB-6 and LB-7 produced more vigorous plants than these check varieties (Table 4). The plant vigor score suggested that LB-6 and LB-7 have the capability to grow faster in all agro-ecologies of Bangladesh.

Late blight resistance of LB-6 and LB-7 was further verified in the 6 locations of RYT, whereas the check variety, Diamant was highly susceptible to Late Blight (Table 6). The susceptible entries showed early senescence as late blight progressed in all

but SYT reduced vigor and ground cover. The resistant clones showed more vigorous plants with later senescence and overall late foliage maturity, as often associated with resistant varieties. The disease also caused a significant reduction in tuber formation in the susceptible genotypes, such that resistant clones/varieties produce more tubers (Table 4).

Tables 5 and 6 show the location-wise average yields of the clones at 65 and 90 DAP, indicating the earliness and performance at full maturity. The clone LB-7 produced the highest yield at 65 DAP followed by the check Diamant, while the clone LB 6 produced the lowest, indicating that the former clone can be used as an early variety, but the latter, LB-6 requires a

**Table 4. Mean vegetative and tuber characteristics of the varieties in RYT**

| Variety            | Plant height (cm) | % Foliage coverage | Plant vigor (1-5) at 60 DAP | No. of stems /plant | No. of Tuber/ plant | Senescence at 75 DAP (1-5 Scale) |
|--------------------|-------------------|--------------------|-----------------------------|---------------------|---------------------|----------------------------------|
| LB-6               | 87.5              | 91.38              | 4.20                        | 3.58                | 8.96                | 1.25                             |
| LB-7               | 83.6              | 95.76              | 4.51                        | 4.45                | 10.46               | 1.75                             |
| Diamant            | 63.7              | 71.25              | 3.37                        | 4.92                | 8.85                | 4.33                             |
| Significance level | **                | **                 | **                          | **                  | **                  | **                               |

\*\*Significant at 0.01 level of probability; NS=Not Significant; Plant vigor (1=low vigor and 5= very high vigor); Senescence 1-5 scale, 5=0-20%; 4=21-40%; 3= 41-60%; 2= 61-80% and 1= 81-100% senescence.

**Table 5. Mean tuber yield of the 2 CIP LB resistant clones at 65 DAP at six trial sites in RYT**

| Location              | Yield at 65 Day (t/ha)                           |       |                 | Average Yield (t/ha) |
|-----------------------|--------------------------------------------------|-------|-----------------|----------------------|
|                       | LB-6                                             | LB-7  | Check (Diamant) |                      |
| Joydebpur             | 5.07                                             | 10.87 | 11.33           | 9.09                 |
| Bogura                | 9.06                                             | 29.77 | 12.58           | 17.14                |
| Munshigonj            | 1.66                                             | 9.15  | 10.25           | 7.02                 |
| Jashore               | 5.90                                             | 20.06 | 14.80           | 13.59                |
| Jamalpur              | 17.69                                            | 26.01 | 20.17           | 21.29                |
| Burirhat              | 13.34                                            | 23.13 | 18.58           | 18.35                |
| Mean                  | 8.79                                             | 19.83 | 14.62           | -                    |
| Level of significance | Genotypes (G) **<br>Environment (E)**<br>G × E** |       |                 |                      |
| CV (%)                | 5.47                                             |       |                 |                      |

**Table 6. Mean tuber yield of the 2 CIP LB resistant clones at 90 DAP at six trial sites in RYT**

| Location              | Yield at 90 Day (t/ha)                           |       |                 | Average Yield (t/ha) |
|-----------------------|--------------------------------------------------|-------|-----------------|----------------------|
|                       | LB-6                                             | LB-7  | Check (Diamant) |                      |
| Joydebpur             | 19.18                                            | 22.34 | 22.73           | 21.42                |
| Bogura                | 27.33                                            | 38.79 | 14.03           | 26.72                |
| Munshigonj            | 46.21                                            | 53.26 | 32.90           | 44.12                |
| Jashore               | 35.79                                            | 49.02 | 30.11           | 38.31                |
| Jamalpur              | 36.38                                            | 48.48 | 35.64           | 40.17                |
| Rangpur               | 28.28                                            | 41.89 | 21.81           | 30.66                |
| Mean                  | 32.20                                            | 42.30 | 26.20           | -                    |
| Level of significance | Genotypes (G) **<br>Environment (E)**<br>G × E** |       |                 |                      |
| CV (%)                | 5.20                                             |       |                 |                      |

mid-length growing season (90 days). The highest yield was consistently observed for LB-7, which continued to stand out in RYT where it averaged 42.30 t/ha and reached 53.26 t/ha at Munshiganj (Table 6). LB 6 averaged 32.20 t/ha in the RYT. The latter clone received additional merit for its red skin color.

The check variety Diamant produced 26.20 tons, respectively on average at the best. LB-6 produced 22.90% higher yield and LB-7 produced 61.41% higher yield, respectively than Diamant in the RYT (Table 6).

Tuber yields in the on-farm trials in the 3 locations ranged from 25.55 to 39.75 t/ha. The average highest yield was found in LB-7 (35.69 t/ha) which produced 44.08% higher yield compared to the check variety Diamant (24.77 t/ha) (Table 8). LB-6 was the 2nd highest average yielder (32.04 t/ha) and produced 29.35% higher yield compared to Diamant (24.77 t/ha) (Table 8).

### Tuber dry matter and Keeping Quality

The tuber dry matter and the keeping of potato tubers are important criteria in selecting and recommending new varieties in Bangladesh. Tuber dry matter contents of LB-6 and LB-7 were 20.42% and 19.00%, respectively, while that of Diamant was 19.88%. In the recent studies (Table 7) CIP clone LB-6 had post-harvest qualities comparable to the checks. Weight loss in CIP clones, LB-6 and LB-7 after 90 days of storage was 16.25 and 32.95% as compared to check variety Diamant, 15.25%. Similarly, rottage

loss was 14.07 and 29.92% as compared to 7.22 % in checks.

### Responses to other diseases

LB-6 and LB-7 each presented less than 10% of plants with symptoms of PLRV or PVY in the RYT trials (Fig. 3). Significant incidence of PVY (nearly 50% in Diamant) indicated that pressure was high enough to cause infection. Thus, although not reported by CIP to carry extreme resistance to PVY (Table 1), these clones may carry partial resistance. Scarce incidence of PLRV was observed (less than 10%) in the test clones or the control. LB-6 is reported to be PLRV resistant, while LB-7 is not. It is likely that symptoms would be found in the latter clone if observations were made during the growth of plants from tubers of plants exposed to the virus and its vectors in a previous season (secondary infection).

### Varietal description

Two clones that consistently performed well for yield and disease resistance – LB-6 and LB-7 - were recommended for variety release. The morphological characteristics (Fig

**Table 7. Tuber dry matter (%) and post-harvest storage behaviour of the candidate potato varieties**

| Variety         | Tuber dry matter at harvest (90 DAP) | Ambient condition (After 90 days of storage) |                |
|-----------------|--------------------------------------|----------------------------------------------|----------------|
|                 |                                      | % Weight loss                                | % Rottage loss |
| LB-6            | 20.42±1                              | 16.25                                        | 14.07          |
| LB-7            | 19.00±1                              | 32.95                                        | 29.92          |
| Diamant (Check) | 19.88±1                              | 15.25                                        | 7.22           |

**Table 8. On-Farm Trial of LB-resistant potato clones in three locations at 90 DAP**

| Variety          | Yield (t/ha) |          |         | Mean yield (t/ha) | % Yield increase over control |
|------------------|--------------|----------|---------|-------------------|-------------------------------|
|                  | Bogura       | Jamalpur | Comilla |                   |                               |
| LB-6 (393280.64) | 25.55        | 31.00    | 39.58   | 32.04             | 29.35%                        |
| LB-7 (393371.58) | 37.78        | 30.13    | 39.17   | 35.69             | 44.08%                        |
| Diamant (Check)  | 10.00        | 28.49    | 35.83   | 24.77             | -                             |

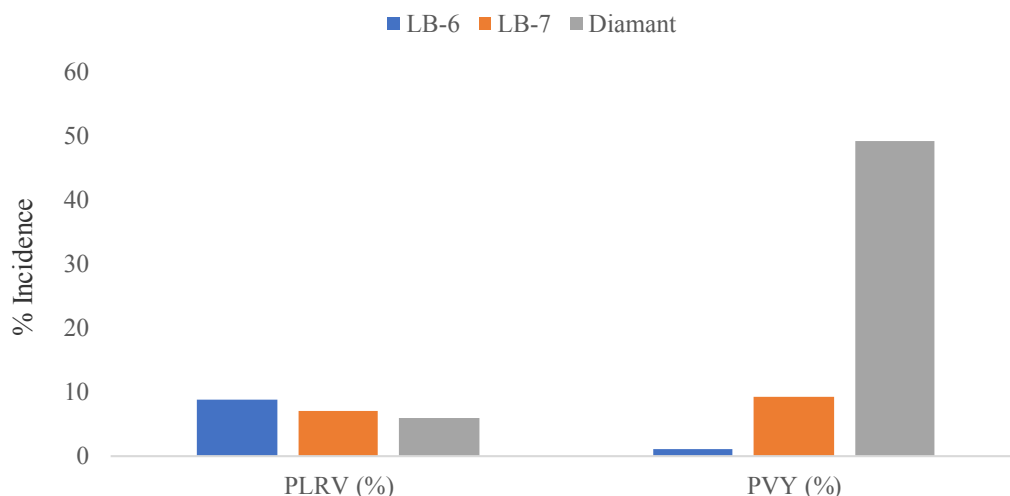


Fig. 3 Virus disease incidence of PLRV and PVY in potato varieties in RYT

Plate 1 & 2) of the two clones (BARI Alu-46 and BARI Alu-53) were assessed by DUS (Distinct, uniform and stable) criteria set out by the National Seed Board of Bangladesh.

### BARI Alu-46

LB-7 (CIP 393371.58) was released in 2013 as Bangladesh's first late blight-resistant potato variety with the name BARI Alu-46 (Figs. 4-5).

### BARI Alu-53

LB-6 (CIP 393280.64) was released in 2014 as Bangladesh's second late blight-resistant variety and named BARI Alu-53 (Figs. 6-7).

### Morphological characteristics of BARI Alu-46 (LB-7, CIP 393371.58) Courtesy International Potato Center (Fig. 5).

| Plant parts           | Characteristics                                                                                                                               |
|-----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| Plant habit           | Medium-sized plant, semi-erect, strong stem, predominantly green.                                                                             |
| Foliage and flowering | Small to medium size shiny green leaves, white flower color and regular flowering habit.                                                      |
| Tubers                | Cream white tubers have an oblong shape, superficial eyes, medium to large tuber sizes, intermediate tuber number per plant, and cream flesh. |
| Sprouts               | Red-purple, cylindrical, pubescence at sprout base weak.                                                                                      |

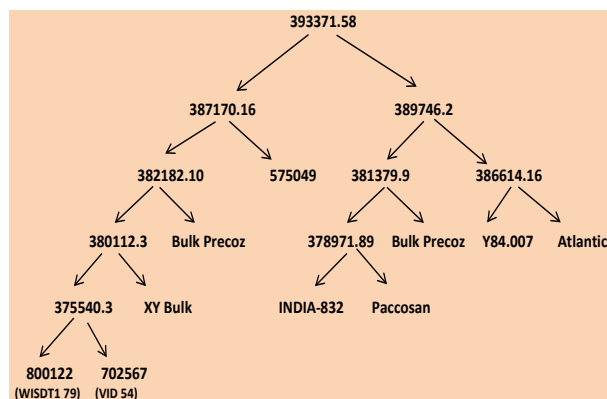


Fig. 4 Parentage, crossing out lines of BARI Alu-46 (LB-7, CIP 393371.58) Courtesy International Potato Center

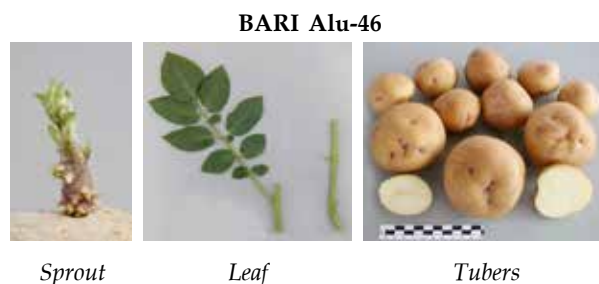


Fig. 5 Morphological characteristics of BARI Alu-46 (LB-7, CIP 393371.58)

### Adaptive trials and farmer's assessment

The average yield of BARI Potato-46 and BARI Potato-53 were 29.87 and 26.81 t/ha, respectively. The tuber yield of BARI Potato-46

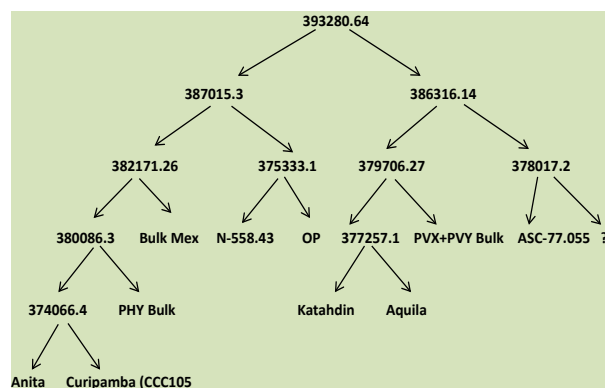


Fig. 6 Parentage, crossing out lines of BARI Alu-53 (LB-6, CIP 393280.64) Courtesy International Potato Center

ranged from 15.30-37.14 t/ha, where the highest tuber yield was recorded in Thakurgaon and the lowest was in Gazipur (Table 9). The tuber yield of BARI Potato-53 ranged from 23.98-34.05 t/ha, where the highest tuber yield was recorded in Thakurgaon and the lowest was in Panchagarh (Table 10).

## DISCUSSION

Potato varieties with resistance to Late Blight could be used to contest the disease.

Table 9. Yield and farmer's assessment of BARI Alu-46 at farmer's fields in 12 locations (188 trials) at 90 DAP under Adaptive trials, 2015-16

| Location            | No. of trial | Yield (t/ha) | Farmers preference     |             |                                                     |
|---------------------|--------------|--------------|------------------------|-------------|-----------------------------------------------------|
|                     |              |              | Late Blight resistance | Plant vigor | Acceptability (Skin color, yield and market access) |
| Thakurgaon          | 23           | 37.14        | 2.50                   | 3.00        | 2.00                                                |
| Dinajpur            | 10           | 18.25        | 2.50                   | 3.00        | 1.00                                                |
| Rangpur             | 50           | 29.39        | 3.00                   | 3.00        | 1.00                                                |
| Bogura              | 22           | 34.09        | 3.00                   | 3.00        | 1.00                                                |
| Rajshahi            | 20           | 28.71        | 2.50                   | 3.00        | 2.50                                                |
| Jashore             | 10           | 30.70        | 3.00                   | 3.00        | 1.50                                                |
| Gazipur             | 5            | 15.30        | 3.00                   | 2.50        | 1.00                                                |
| Munshiganj          | 9            | 32.02        | 3.00                   | 2.00        | 1.00                                                |
| Comilla             | 19           | 32.12        | 3.00                   | 2.00        | 1.00                                                |
| Jamalpur            | 10           | 34.06        | 3.00                   | 2.50        | 1.50                                                |
| Sherpur             | 10           | 33.15        | 3.00                   | 2.00        | 2.00                                                |
| Total location (12) | 188          | 29.87 ± 6.62 | 2.86                   | 2.64        | 1.41                                                |

Late Blight Resistance Scale 1-3, 3: Excellent, 2: Medium and 1: Susceptible; Plant vigor Scale 1-3, 3: Highly vigorous; 2: Medium vigor; 1: Average vigor; Acceptability scale 1-3: 3: High; 2: Medium; 1: Low

## Morphological characteristics of BARI Alu-53 (LB-6, CIP 393280.64) Courtesy International Potato Center (Fig. 7).

| Plant parts           | Characteristics                                                                                                             |
|-----------------------|-----------------------------------------------------------------------------------------------------------------------------|
| Plant habit           | Medium-size plant, semi-erect, strong stems.                                                                                |
| Foliage and flowering | Small to medium size leaves purple flower color and regular flowering habit.                                                |
| Tubers                | Oblong shape, red skin color, superficial eyes, medium to large tuber sizes, high tuber number per plant, pale yellow flesh |
| Sprouts               | Purple                                                                                                                      |

### BARI Alu-53

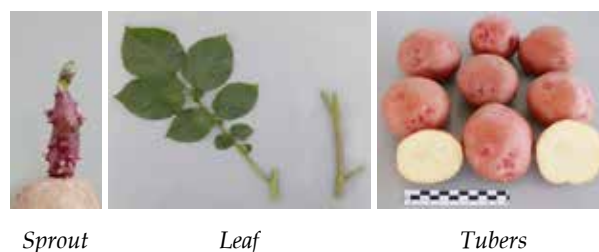


Fig. 7 Morphological characteristics of BARI Alu-53 (LB-6, CIP 393280.64)

**Table 10. Yield and farmer's preference of BARI Alu-53 in 62 adaptive trials in farmer's fields in 12 locations at 90 DAP, 2015-16**

| Location           | No. of trial | Yield (t/ha) | Farmers preference     |             |                                                     |
|--------------------|--------------|--------------|------------------------|-------------|-----------------------------------------------------|
|                    |              |              | Late Blight resistance | Plant vigor | Acceptability (Skin color, yield and market access) |
| Thakurgaon         | 7            | 34.05        | 2.0                    | 2.0         | 2.5                                                 |
| Rangpur            | 10           | 27.59        | 2.5                    | 2.5         | 2.0                                                 |
| Bogura             | 28           | 28.79        | 2.5                    | 3.0         | 2.5                                                 |
| Jashore            | 10           | 28.22        | 3.0                    | 2.0         | 3.0                                                 |
| Panchagarh         | 7            | 23.98        | 2.5                    | 2.5         | 3.0                                                 |
| Total location (6) | 62           | 26.81± 5.30  | 1.9                    | 1.4         | 1.6                                                 |

Late Blight Resistance Scale 1-3, 3: Excellent, 2: Medium and 1: Susceptible; Plant vigor Scale 1-3, 3: Highly vigorous; 2: Medium vigor; 1: Average vigor; Acceptability scale 1-3: 3: High; 2: Medium; 1: Low

The use of race-specific resistance has turned out not to be stable because *P. infestans* is able to overcome this type of resistance. Race non-specific resistance is expected to be more stable but, unfortunately, this type of resistance to *P. infestans* is associated with late foliage maturity (Johnson, 1979). In our study, CIP bred LB resistant clones showed late foliar maturity with more vigorous plants and delayed senescence as compared to the control varieties (Table 6). Nevertheless, our data on yield at 90 DAP enables their classification as medium maturing, and not late in terms of tuber set and bulking. Additionally, BARI Alu-46 yielded well at 65 DAP, qualifying it as early. The implications of the vigorous plant habit on harvesting and storage of tubers may need further research in order to minimize weight loss and roting, but it is not seen as detrimental to the acceptance of new varieties in Bangladesh.

The presence of an aggressive, variable population of the pathogen may interfere with the stability of partial resistance (Latin *et al.*, 1981) and a move towards the greater aggressive populations of *P. infestans* will result in the overall reduction in the resistance of potato cultivars. In addition, differential changes in the ranking of partially resistant cultivars after exposure to different genotypes

of the pathogen may arise (Leonard and Moll, 1979). Since both partial and race-specific resistance can fall apart following the appearance and spread of more aggressive pathogen strains, using isolates from the most aggressive populations is helpful in evaluating resistance. In practice, testing the accessions across locations with diverse pathogen populations may easily achieve this.

Hossain *et al.* (2018) studied late blight resistance in detached leaves of nine potato varieties and found that LB-6 and LB-7 possessed much better resistance compared to the checks and other varieties. Saha *et al.* (2018) evaluated 35 potato varieties in field plots for three years (2015-16, 2016-17 and 2017-18), and found that the variety BARI Alu-46 (LB-7), imported varieties Alouette and Carolus were highly resistant; BARI Alu-53 (LB-6) and BARI Alu-77 were moderately resistant, and a few were partially resistant to late blight. Rahman *et al.* (2018) also found similar results for these two varieties. Consistent performance including low AUDPC and sparse sporulation on slight lesions over multiple years and plot locations in several environments suggest that BARI Alu-53 and BARI Alu-46 may carry a durable type of resistance to late blight. However, this does not discount the need

for continued vigilance including occasional fungicide applications where late blight is seen, as this may help limit changes in the pathogen population.

Efforts to control virus diseases during evaluation included chemical control of aphids and the use of healthy tuber seeds from TCRC research stations to plant each trial. Thus, the incidence of PLRV was low, as observed in RYT. LB-6 and LB-7 showed lower incidences of PVY than did Diamant, although neither carried extreme resistance according to the CIP catalog of advanced potato clones. Table 1 indicates that a number of the test clones carry extreme resistance to PVX and/or PVY, and resistance to infection or tolerance to PLRV, but not all of these performed well enough for variety release in Bangladesh. Notably, those that did are both PVX resistant and LB-6 is resistant or tolerant to PLRV. The use of varieties resistant to PVX, PLRV, and PVY can reduce net losses from potato production due to reduced yield, tuber defects, and downgrading of seed crops (Solomon-Blackburn and Barker, 2001). Bangladesh's current variety trials include CIP-bred clones with multiple virus resistance, the release of which may contribute to increasing the country's seed production capacity with positive economic and environmental consequences.

## CONCLUSION

From the results on farmers' fields and those on-stations, it can be concluded that LB-6 and LB-7 possess good resistance to the devastating disease late blight and produce equivalent or higher yields than predominant commercial varieties in diverse agro-ecological regions of Bangladesh. Accordingly, the National Seed Board of Bangladesh released LB-7 as BARI Alu-46 and LB-6 as BARI Alu-53 in 2014 and 2015, respectively. But Breeders as well

as Pathologists, suggest that especially for varieties with late foliage maturity, there should be one or two fungicide sprays when conditions are conducive to Late Blight so that the pathogen cannot complete many life cycles and will be less likely to overcome the resistance of the varieties. These are the first Late Blight resistant varieties of Bangladesh, identified through testing and selection from CIP bred materials. Continued stable performance has been observed across extensive adaptive trials in recent years. TCRC is currently producing quality seed of these two Late Blight Resistant Potato varieties to distribute among growers, along with promotional activities and monitoring of end-users perceptions and possible implications on system productivity, crop, and disease management.

Population development and stability analysis in tropical and subtropical environments of Peru identified promising and well-adapted candidate varieties for Bangladesh. Nevertheless, the >25 years from crossing to the releases reported here call for more dynamic germplasm exchange and assessment so that national programs may avail the latest advances inbreeding in shorter time frames. Prior to its release in Bangladesh as *BARI Alu-46*, CIP 3933371.58 was released in Peru (2007) as Chugmarina, in Kenya as Kenya MPYA, and in Ethiopia as Belete. CIP 393371.58 And CIP393280.64 have proven to be excellent female and male parents, respectively, in CIP's efforts to expand the adaptation of its B3 population with high levels of late blight resistance to warmer climates of mid-elevation tropic and sub-tropical environments (Gastelo *et al.*, 2014). They have also produced high-performing progeny in TCRC's crossing program aimed at developing mid- and short-duration varieties with multiple diseases and stress resistances.

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## CONFLICTS OF INTEREST

The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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# SENSITIVITY OF POTATO CULTIVARS TO FOMESAFEN AND METRIBUZIN

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**ABSTRACT:** The objective of this research was to evaluate the sensitivity of 3 potato cultivars (different ripening periods) to fomesafen (300 g/ha a.i.) and metribuzin (980 g/ha a.i.) herbicides applied preemergence (PRE). The experiments were conducted during 2020 and 2021 in the Leningrad region of the Russian Federation. The application of herbicides at all three potato cultivars caused slight yellowing of tips of the leaves (less than 5%). This symptom of phytotoxicity was more noticeable in the early season cultivars Udacha (ripening time from 65 days) and Nevsky (ripening time from 75 days). The negative effect of herbicides on plant height was demonstrated in arid conditions (in 2021), when after applying fomesafen and metribuzin there was a significant delay in plant growth in two cultivars (Udacha and Avrora) at 7 and 14 days after emergence (DAE). By 28 DAE, the plant height of all three cultivars after herbicide treatments and in the nontreated check were equalized (differences did not exceed 10%). Despite the observed symptoms of phytotoxicity, none of the herbicide treatments in both years didn't show a statistically significant negative effect of herbicides on potato yield, indicating the high regenerative capacity of potatoes.

**KEYWORDS:** herbicide, phytotoxicity, crop injury, *Solanum tuberosum*

## INTRODUCTION

Potato is an integral part of the diet in countries of the Nordic region (such as Sweden, Norway, Finland, Russia). Climatic conditions in these countries contribute to the wide spread of the crop (relatively short and intense seasons with long day length), as well as specific consumer preferences. At the same time, potato has the highest yield potential of all crops in the Nordic region (Eriksson *et al.*, 2016). One of the important factors limiting potato yields is the presence of weeds on agricultural land (Barbas and Sawicka 2020). Weeds compete for nutrients and negatively effect on plant growth and crop yield (Mondani *et al.*, 2011; Dhaliwal *et al.*, 2021).

Weeds should be controlled in the early growth stages of the crop, when they are most harmful (Karimmojeni *et al.*, 2014). Besides, control of some weeds in the later growth stages is difficult due to their morphological

characteristics, such as deep root system or underground shoots in perennial weeds (Siblani and Haidar 2017). Experiments conducted by Isik *et al.* (2015) showed that the critical period of weed control on potatoes is from 8 to 66 days after emergence. Ignoring weeds during this period can lead to a significant reduction in potato yield and tuber quality.

Weeds can be eliminated from potato plantings at the beginning of the crop's vegetation period by using herbicides, which have become an indispensable and permanent element in potato cultivation technologies. One of the most commonly used herbicides on potatoes is metribuzin. However, despite its high effectiveness against weeds, it can have a negative effect on some potato cultivars (Friesen and Wall 1984; Arsenault and Ivany 1996; Arsenault and Ivany 2001; Alebrahim *et al.*, 2012). Because of this negative effect, there is a search for active ingredients that can improve the existing assortment of herbicides. One of the ways of such improvement is to

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expand the range of protected crops for well-known products.

Fomesafen (PPO Inhibitor (Group 14)), which has residual action, is an effective means to control dicotyledonous weeds in crops (Wu *et al.*, 2018). This herbicide is most widely used in soybean crops, but attempts are being made to use it in other crops as well, including: bean, vegetable soybean, cotton, corn, rice, tomatoes (Wilson 2005; Williams and Nelson 2014; Oliveira Neto *et al.*, 2015; Galon *et al.*, 2018; Sperry *et al.*, 2019; Lawrence *et al.*, 2021; Yu *et al.*, 2021). However, in practice the use of fomesafen in addition to reducing the number of weeds, can also have an adverse effect on protected crops and even on succession crops (Barkley *et al.*, 2016; Li *et al.*, 2018; Schmitt *et al.*, 2019; De Souza Cruz *et al.*, 2020; Chen *et al.*, 2021; Hand *et al.*, 2021). At the same time, fomesafen may be less toxic to crops than other herbicides (chlorimuron-ethyl, glyphosate, paraquat, atrazine) (Do Amaral *et al.*, 2018). Researches have shown that potato resistance to herbicides can be directly related to the characteristics of some cultivars (Wilson *et al.*, 2002; Pszczółkowski *et al.*, 2020). In this regard, the commercial use of fomesafen on potatoes should be preceded by a study of the sensitivity of potato cultivars to this active ingredient. It is important to evaluate such sensitivity compared to metribuzin. The aim of this research was to evaluate the response of three of potato cultivars (different ripening periods) to fomesafen and metribuzin applied preemergence (PRE). Accordingly, the objective of the trials was to assess the effect of herbicides on potato germination, plant height, number of stems and leaves, and crop yield.

## MATERIALS AND METHODS

Trials were conducted in 2020 and 2021 in the Leningrad region of the Russian Federation

(59.74 'N, 30.42 'E) on the experimental field of the All-Russian institute of plant protection (VIZR).

### Characteristics of the experimental site

The soil of the experimental site was sod-podzolic, with 3.5% organic matter in the arable layer, pH=6.3. Previous crop in both trial years was potato.

Soil treatment included disking, plowing, cultivation, cutting furrows. In spring NPK fertilizer at the rate of 200 kg/ha was applied into the soil before planting potato.

### Measures for the maintenance of experimental site

Two hilling and applying 2.5 kg/ha fungicide Ridomil Gold MC, WG (mancozeb, 640 g/kg + mefenoxam, 40 g/kg) against late blight (*Phytophthora infestans* (Mont.) de Bary) were made during the trials.

### Weather conditions

According to the data presented in the Table 1, the weather in both years of the experiment was generally hotter and drier compared to the average long-term data. In general, the air temperature in the growing season of 2020 was 7% higher than the average long-term value, and the humidity was 8% lower. The 2021 data differed more: the temperature was 21% higher than the long-term average, the humidity was 16% lower, and the amount of precipitation was 23% lower. All this had a direct impact on the results obtained in the experiments. Due to more arid conditions and, as a consequence, stress for potato plants, the expression of phytotoxicity in the second year of the study was more intense.

### Conditions for conducting experiments

The experiments were based on the method of randomized blocks in three

Table 1. Weather conditions during the experiments (2020, 2021)

| Indicators                            | Months and decades |      |      |      |      |      |      |      |      |        |      |      |
|---------------------------------------|--------------------|------|------|------|------|------|------|------|------|--------|------|------|
|                                       | May                |      |      | June |      |      | July |      |      | August |      |      |
|                                       | 1                  | 2    | 3    | 1    | 2    | 3    | 1    | 2    | 3    | 1      | 2    | 3    |
| Air temperature, °C long-term average | 8.5                | 11.1 | 12.3 | 14.3 | 15.7 | 16.6 | 17.3 | 17.8 | 17.9 | 17.2   | 16.0 | 14.4 |
| 2020                                  | 9.1                | 6.5  | 11.8 | 16.1 | 19.8 | 20.1 | 17.1 | 17.4 | 16.6 | 18.2   | 16.0 | 16.1 |
| 2021                                  | 5.7                | 17.6 | 11.4 | 18.0 | 19.8 | 24.2 | 23.4 | 24.2 | 19.6 | 17.3   | 18.0 | 13.9 |
| Precipitation, mm long-term average   | 10.3               | 12.2 | 14.7 | 13.8 | 17.0 | 24.5 | 22.1 | 21.2 | 22.7 | 24.2   | 20.4 | 24.8 |
| 2020                                  | 7.0                | 27.6 | 8.8  | 13.6 | 8.5  | 10.0 | 17.6 | 5.3  | 43.9 | 15.5   | 0.3  | 78.7 |
| 2021                                  | 45.0               | 40.9 | 38.1 | 0    | 5.8  | 19.6 | 7.9  | 10.1 | 25.9 | 87.4   | 51.6 | 27.2 |
| Air humidity, % long-term average     | 67                 | 73   | 71   | 66   | 68   | 71   | 72   | 74   | 76   | 77     | 79   | 82   |
| 2020                                  | 58                 | 68   | 52   | 68   | 62   | 56   | 70   | 67   | 75   | 73     | 67   | 77   |
| 2021                                  | 73                 | 60   | 69   | 51   | 55   | 61   | 52   | 54   | 59   | 74     | 71   | 80   |

replications. The plot size was 2 m<sup>2</sup>. The herbicides were applied with Resistent 3610 backpack sprayer. To prepare the working liquid, 250 l/ha of water were used. The scheme of the experiments included the use of the following herbicides before the germination of potato plants (PRE) (Table 2.).

We have selected three cultivars of table potatoes, differing in terms of maturation and the size of the bushes: 1. Cv. Udacha. Ripening time from 65 days. The plant is medium-height, semi-spreading. Leaves with large lobes, dark green. The corolla is white. The tuber is light beige. 2. Cv. Nevsky. Ripening time from 75 days. The plant is semi-erect, of medium height. The leaf is medium-sized, wavy margin is weak. The corolla is white. The tuber is light beige. 3. Cv. Avrora. Ripening time from 85 days. The plant is tall, semi-erect. The corolla is large, red-purple.

In order to eliminate the negative effect of weeds on potatoes, all plots of the experiments (with herbicides and nontreated check) were regularly weeded manually until harvest.

In accordance with PP 1/135 (4) EPPO (2014), we planned following counts: 1. Evaluation of possible delayed emergence of plants with preemergence herbicide treatment was performed by counting the number of plants on the plot after the appearance of mass seedlings. Since the shoots appeared unevenly, the date when the area of the plots was filled with shoots by 50% was considered the day of the emergence of seedlings; 2. Visual assessment of herbicide selectivity separately for each type of damage (where 0% – without damage, 100% – complete death of plants) at 2, 7, 14 and 28 days after the emergence (DAE); 3. Observation of the stages of crop growth at 2, 7, 14 and 28 DAE; 4. Determination of the density of the crop,

Table 2. Herbicides information

| Products name | Active ingredients (a.i.) | Content | Formulation          | Application rates |          |
|---------------|---------------------------|---------|----------------------|-------------------|----------|
|               |                           |         |                      | products          | a.i.     |
| Nexus         | Fomesafen                 | 24%     | Water solution (WS)  | 1.25 l/ha         | 300 g/ha |
| Lazurit       | Metribuzin                | 70%     | Wettable powder (WP) | 1.4 kg/ha         | 980 g/ha |

as well as the height, number of stems and leaves at 2, 7, 14 and 28 DAE; 5. Counting the crop yield from each plot of the experiment.

Harvesting was carried out manually, by digging out bushes from 1 linear meter. The data obtained in the experiments were analyzed using ANNOVA F test.

## RESULTS AND DISCUSSION

### Visual signs of phytotoxicity

Potato injury caused by fomesafen and metribuzin herbicides occurred on potato plants in both years of the study. The application of fomesafen caused yellowing of the edges of potato leaves (Fig 1). Metribuzin, in addition to yellowing, caused “marbling” of leaves.

In 2020, injuries caused by herbicide were observed in all cultivars, but the number of potato seedlings with these injuries was different. After 2 days after the appearance of mass shoots (DAE) an average of 1.7 plants Udacha cultivar with injuries from both herbicides were noted (Table 3). At that time, the number of plants Nevsky cultivar injured by herbicides was lower: 1 plant – with fomesafen and 1.3 – with metribuzin. On the Avrora cultivar, the values were the lowest:

0.3 and 0.7 plants with injuries on average on the plot. Visual signs of phytotoxicity were observed within a week. Subsequently, potato plants of all cultivars recovered and two weeks after the mass emergence of seedlings (14 DAE), all potato plants were without any injury. It should be noted that the number of sprouted potato plants in the experimental plots varied significantly during the counts, but statistically these differences were insignificant in both years of research.

In 2021, statistically significant injury from fomesafen to potatoes cultivar Udacha was observed at the 2 DAE (in average 2 injured plants per plot). During the next count, potato injury two cultivars was observed from both fomesafen and metribuzin herbicides. On the Udacha cultivar, plants with injuries were on average 1.0 and 0.7, and on the Nevsky cultivar – 0.3 and 0.7, respectively. As in the first year of studies, all injured potato plants recovered in 2 weeks after emergence.

### Plant height

In 2020, the height of potato plants of all three cultivars with herbicide application was generally not inferior to the height of the nontreated check.



A. *fomesafen* – 300 g/ha a.i. (PRE)



B. nontreated check

Figure 1. Visual injuries of the potato cultivar Udacha caused by fomesafen one week after emergence (2021)

Table 3. Visible injury on potato after herbicides treatments (2020, 2021)

| Treatments (g/ha<br>a. i.) | 2020   |                  |        |                  |        |                | 2021   |                |        |                  |        |                  |
|----------------------------|--------|------------------|--------|------------------|--------|----------------|--------|----------------|--------|------------------|--------|------------------|
|                            | 2 DAE  |                  | 7 DAE  |                  | 14 DAE |                | 28 DAE |                | 2 DAE  |                  | 7 DAE  |                  |
|                            | TNOP   | PWI              | TNOP   | PWI              | TNOP   | PWI            | TNOP   | PWI            | TNOP   | PWI              | TNOP   | PWI              |
| <b>Udacha</b>              |        |                  |        |                  |        |                |        |                |        |                  |        |                  |
| fomesafen (300) PRE        | 10.5** | 1.7 <sup>b</sup> | 15.0** | 0.7 <sup>b</sup> | 15.0** | 0 <sup>a</sup> | 15.0** | 0 <sup>a</sup> | 16.3** | 2.0 <sup>b</sup> | 21.3** | 1.0 <sup>a</sup> |
| metribuzin (980) PRE       | 8.6**  | 1.7 <sup>b</sup> | 14.7** | 1.3 <sup>b</sup> | 14.7** | 0 <sup>a</sup> | 14.7** | 0 <sup>a</sup> | 17.0** | 0 <sup>a</sup>   | 20.7** | 0.7 <sup>a</sup> |
| nontreated check           | 8.0**  | 0 <sup>a</sup>   | 14.3** | 0 <sup>a</sup>   | 14.3** | 0 <sup>a</sup> | 14.3** | 0 <sup>a</sup> | 15.7** | 0 <sup>a</sup>   | 19.0** | 0 <sup>a</sup>   |
| <b>Nevsky</b>              |        |                  |        |                  |        |                |        |                |        |                  |        |                  |
| fomesafen (300) PRE        | 11.1** | 1.0 <sup>b</sup> | 16.7** | 2.0 <sup>b</sup> | 16.7** | 0 <sup>a</sup> | 16.7** | 0 <sup>a</sup> | 13.3** | 0 <sup>a</sup>   | 18.7** | 0.3 <sup>a</sup> |
| metribuzin (980) PRE       | 11.7** | 1.3 <sup>b</sup> | 16.7** | 0.3 <sup>b</sup> | 16.7** | 0 <sup>a</sup> | 16.7** | 0 <sup>a</sup> | 15.7** | 0 <sup>a</sup>   | 17.0** | 0.7 <sup>a</sup> |
| nontreated check           | 10.1** | 0 <sup>a</sup>   | 16.0** | 0 <sup>a</sup>   | 16.0** | 0 <sup>a</sup> | 16.0** | 0 <sup>a</sup> | 14.7** | 0 <sup>a</sup>   | 18.3** | 0 <sup>a</sup>   |
| <b>Avrora</b>              |        |                  |        |                  |        |                |        |                |        |                  |        |                  |
| fomesafen (300) PRE        | 7.1**  | 0.3 <sup>b</sup> | 16.3** | 0.3 <sup>b</sup> | 16.3** | 0 <sup>a</sup> | 16.3** | 0 <sup>a</sup> | 6.3*   | 0 <sup>a</sup>   | 14.7** | 0 <sup>a</sup>   |
| metribuzin (980) PRE       | 11.4** | 0.7 <sup>b</sup> | 18.0** | 0.7 <sup>b</sup> | 18.0** | 0 <sup>a</sup> | 18.0** | 0 <sup>a</sup> | 11.3** | 0 <sup>a</sup>   | 16.7** | 0 <sup>a</sup>   |
| nontreated check           | 9.2**  | 0 <sup>a</sup>   | 15.3** | 0 <sup>a</sup>   | 15.3** | 0 <sup>a</sup> | 15.3** | 0 <sup>a</sup> | 10.3** | 0 <sup>a</sup>   | 16.3** | 0 <sup>a</sup>   |

TNOP - total number of plants on the plot; PWI - plants with injury on the plot. \*\*insignificant differences at  $p=0.05$  level; means followed by distinct letters differ from each other by the F test, respectively.

Potato plants of the Udacha cultivar after using fomesafen grew even faster than the nontreated check: during the first accounting, the excess height values were 39% (Fig 2). When metribuzin was applied, the height of the plants was at the nontreated check level, and the range of variation was from 2 to 5%.

The height of potato plants of the Nevsky cultivar did not depend on the application of both herbicides: the range of changes in height relative to the nontreated check was within the interval of 1 to 15%.

On the Avrora cultivar, application of metribuzin led to a significant (23%) delay in plant height compared to nontreated check at the first accounting. Next count values were in the range from 1 to 10%.

In 2021, potato injury caused by the application of herbicides was significantly stronger.

Thus, on the cultivar Udacha there was a delay in the height of potato plants after the application of both herbicides. On the 7 DAE, this delay was 35% (with fomesafen) and 23% (with metribuzin). Subsequently, the differences leveled off and at the 14 DAE the delay in height was significant after applying metribuzin (14%). On the Nevsky cultivar in the initial period (7 DAE), there was a delay plant height after application of fomesafen (by 16%). After next 7 days, the situation changed and, conversely, the height of plants treated with herbicides was higher, and the range was from 1 to 12%.

On the Avrora cultivar, the delay in height of plants after herbicides treatments was the strongest. After fomesafen treatment, it was 44% (7 DAE) and 24% (14 DAE). After using metribuzin: 31% and 14%, respectively. Thus, the height of plants of this cultivar after all treatments was leveled only at 28 DAE.

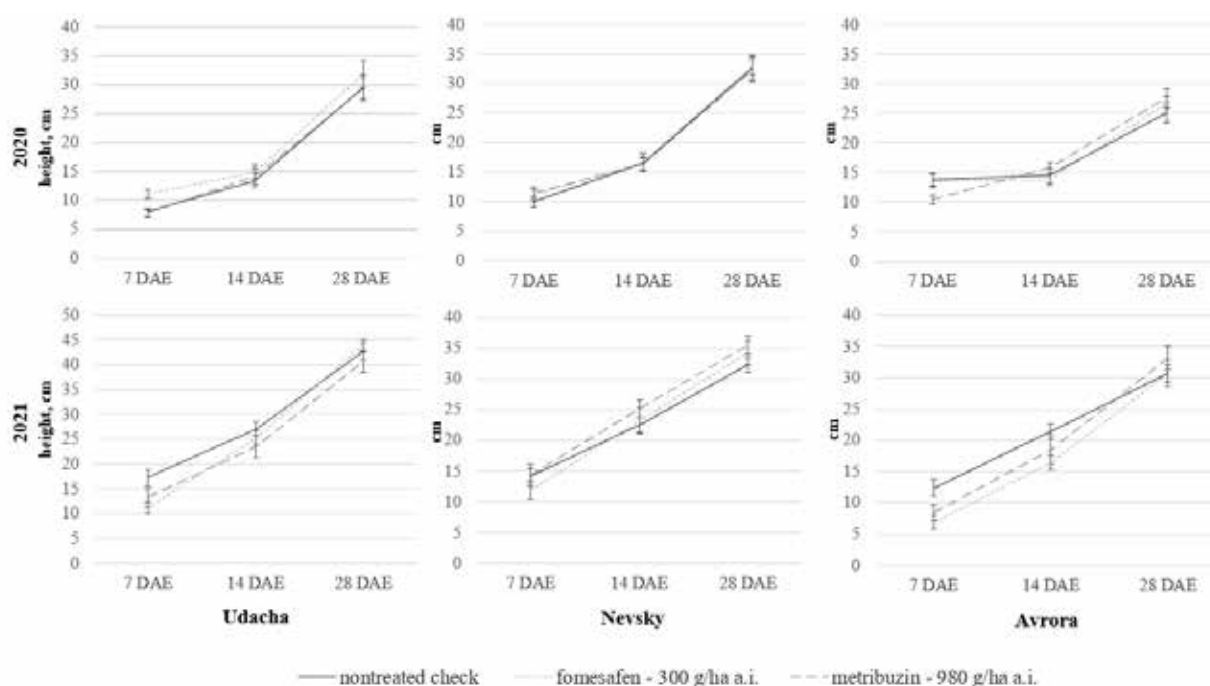


Figure 2. Height of potato after herbicides treatments (2020, 2021)

## Potato tuber yield

In 2020, the yield of all three potato cultivars was at the same level – from 24.1 (for the Avrora cultivar) to 25.5 t/ha (for the Udacha cultivar). In 2021, the yield of the cultivars Udacha and Nevsky was noticeably higher – 28.0 and 30.2 t/ha, respectively. And the potato cv. Avrora did not increase – 22.8 t/ha.

Despite the high variety of the results, none of the herbicide's treatments lead a significant reduction in crop yields (Table 4). The only significant difference was recorded

in 2020: after metribuzin treatment the yield was significantly higher than the nontreated check, but this trend was not confirmed the following year.

The results of the experiments allow us to state that the application of fomesafen and metribuzin can cause lightening and yellowing of the leaf tips of all studied potato cultivars. At the same time, the degree of such impact varies depending on the cultivar.

Although plant injuries were observed at all three cultivars in 2020, the number of injured plants of the cultivars Udacha

Table 4. Potato yield after herbicides treatments (2020, 2021)

| Treatments (g/ha a.i.) | Yield of potato cultivars, tons per hectare |      |        |      |        |      |
|------------------------|---------------------------------------------|------|--------|------|--------|------|
|                        | Udacha                                      |      | Nevsky |      | Avrora |      |
|                        | 2020                                        | 2021 | 2020   | 2021 | 2020   | 2021 |
| fomesafen (300) PRE    | 24.0                                        | 34.9 | 25.4   | 36.7 | 21.2   | 25.9 |
| metribuzin (980) PRE   | 30.7                                        | 29.8 | 24.7   | 37.0 | 19.4   | 21.4 |
| nontreated check       | 25.5                                        | 28.0 | 24.8   | 30.2 | 24.1   | 22.8 |
| LSD ( $p=0.05$ )       | 2.1                                         | 9.4  | 4.0    | 14.2 | 7.3    | 10.7 |

and Nevsky was greater compared to the cultivar Avrora. In 2021, injuries of potato plants were observed mainly at the cultivar Udacha and only in the second count their insignificant number was observed at the cultivar Nevsky.

It should be noted that visual signs of injuries in both years of the research were shown for a short period of time, not exceeding one week. These results are compatible with the data obtained by other authors who have studied herbicide phytotoxicity. It was shown that, clomazone presented phytotoxicity symptoms at 10 days after emergence (DAE) and the plants recovered from these symptoms at 30 DAE (Luz *et al.*, 2018; Abdallah *et al.*, 2021). Another author also reports that the crop can recover from the injury caused by fomesafen: minimal crop injury was observed 7 and 14 DAT and none crop injury at 42 DAT (Mohseni-Moghadam *et al.*, 2017).

In 2020, the height of potato plants of all three cultivars with application of herbicides was generally not inferior to the height of plants in the nontreated check. And the negative effect was noted in 2021: after application of both metribuzin and fomesafen herbicides a significant delay in plant growth of two cultivars (Udacha and Avrora) was observed at 7 and 14 DAE.

As already noted, the weather conditions during the experiments in 2020 and 2021 were drier and hotter compared to the average long-term conditions. At the same time, the weather observed directly during the beginning of experiment, treatments and the first counts (4 decades, starting from the second decade of June) was even more extreme. Thus, the average temperature during this period was 10% higher than the long-term average in 2020 and 36% higher in 2021; the amount of precipitation in both

years was twice lower than the average long-term value; and the humidity in 2020 was 11% lower, and in 2021 – 22%.

In this context, it can be assumed that the hot and arid conditions of 2021 caused stronger phytotoxicity symptoms in the form of stunted plant growth. This is compatible with the results of other authors. In general cases, tolerance or susceptibility of a plant to herbicides varies depending on the product, application time (pre or postemergence), dose used, characteristics of soil and plant (related to absorption, translocation and metabolism of herbicide, alteration of plant of action) and environmental conditions (Correia and Carvalho 2019; Colquhoun *et al.*, 2021). In particular, it has been shown that environmental conditions that have a direct effect on crop plants (such as rainfall, or on the contrary, arid conditions) contribute to a strong phytotoxicity of fomesafen (Main *et al.*, 2012; Cieslik *et al.*, 2014).

It should be emphasized that as a result, the range of variability in plant height of all three cultivars when both herbicides were applied as well as in the nontreated check, did not exceed 10% by 28 DAE (all values were statistically at the same level).

This fact, along with the absence of a significant effect of herbicides on the number of stems and leaves, which is also confirmed by Fonseca *et al.* (2018) data, indicates a great regenerative ability of potatoes, regardless of their cultivar characteristics.

Visual observations of potato growth stages showed no significant signs of potato stunting in the plots with herbicide application compared to the nontreated check. The growth of potato plants of all three cultivars in both years after herbicides applied was in accordance with their biological characteristics.

The regenerative abilities of potatoes, we revealed in experiments, are reflected in the analysis of such an integral indicator as crop yield. Despite the appearance of yellow spots on the leaves, as well as a decrease in potato height in the early growth stages of potato compared to the nontreated check; no statistically significant negative effect of herbicides was detected in both years of research.

These data correlate with the data obtained by scientists conducting experiments with metribuzin and fomesafen on soybean. Also, as in our experiments, soybean injury resulting from fomesafen and metribuzin treatments can be observed in the initial period, but no yield loss occurred with any herbicide application (Priess *et al.*, 2020; Arsenijevic *et al.*, 2021).

## CONCLUSION

The preemergence application of fomesafen – 300 g/ha a.i. and metribuzin – 980 g/ha a.i. can cause symptoms of phytotoxicity in the form of yellowing of leaf tips in all three studied potato cultivars (especially Udacha and Nevsky cultivars). The negative effect of herbicides on plant height was most demonstrated under arid conditions (in 2021), when after the application of both herbicides there was a significant delay in plant growth of two cultivars (Udacha and Avrora) at 7 and 14 DAE. By 28 DAE, the height of plants of all three cultivars with herbicide application and in the nontreated check was leveled (the differences did not exceed 10%). Despite the observed signs of plant injuries, no statistically significant negative herbicides effects at yield were detected in both years of the study, which indicates a great regenerative ability of potatoes.

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## CONFLICTS OF INTEREST

The authors confirm that this manuscript has no conflicts of interest

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# STRATEGIES FOR AGRONOMIC BIOFORTIFICATION OF POTATO TUBERS WITH ZINC

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**ABSTRACT:** Current study explored the possibility of increasing zinc (Zn) content in potato tubers by foliar, seed tuber soaking, and soil application of Zn fertilizers. During first year, a single application of 5 kg Zn ha<sup>-1</sup> through zinc sulphate (ZnSO<sub>4</sub>) increased the Zn concentration by ~30 % followed by split application of ZnSO<sub>4</sub> (19.6%), and a single application of 1 kg Zn as Zn-EDTA (17.6%) in whole tubers. Single and split soil application of either zinc sulphate (5 kg ha<sup>-1</sup>) or zinc-EDTA (1.0 kg Zn ha<sup>-1</sup>), foliar application (ZnSO<sub>4</sub>) and soaking of seed tubers in zinc sulphate solution before planting also increased its concentration significantly in tuber peels. During 2<sup>nd</sup> year of experimentation, a single soil application of zinc sulphate (5 to 10 kg Zn ha<sup>-1</sup>), Zn-EDTA (1 to 2 kg Zn ha<sup>-1</sup>) increased the Zn concentration in peeled (tuber flesh) as well as unpeeled whole tuber significantly. Application of 2 kg zinc as Zn-EDTA resulted in highest increase of 4.4 mg kg<sup>-1</sup> Zn (25.7%) in tuber flesh which was comparable with 10 kg Zn as ZnSO<sub>4</sub> (24.9%). On application rate basis, compared to ZnSO<sub>4</sub>, the 5-times lesser quantity of chelated Zn resulted in equivalent increase in tuber Zn concentration. Since, the bioavailability of Zn from potatoes is high, the soil application of Zn fertilizers during the initial crop growth stage, as revealed by this study, can be adopted as a simple strategy to increase its content in tubers for addressing Zn - related malnutrition issues.

**KEYWORDS:** Biofortification, potato, tuber, flesh, peel, zinc content, zinc fertilizers

## INTRODUCTION

Micronutrient malnutrition is the most widespread nutritional problem worldwide (Stein, 2010). Amongst micronutrients, zinc (Zn) is critical to human immune system and affects the function of more than 300 biological enzymes (McCall *et al.*, 2000). Its deficiency is highly prevalent in developing and developed countries (Gibson, 2012). Zn deficiency affects plant development and nutrition in around one-third of the world's soils, and low Zn concentrations in edible plant portions also have an impact on human Zn nutrition (Cakmak and Kutman, 2018).

Potato tubers may have a high zinc bioavailability, making them a key crop in the fight against Zn deficiency (White *et al.*, 2009). Since there are wide variations in Zn content

of tubers among Indian potato cultivars and germplasm (Sharma *et al.*, 2017, Dalamu *et al.*, 2017), the development of genetically biofortified cultivars that are commercially viable takes a lot of time. Zn-deficiency is highly prevalent in developing countries in general, and the rice dominated north-Indian plains in particular (Heba *et al.*, 2021), where potato is an important *Rabi* season crop. Hence, agronomic biofortification through the use of agricultural techniques e.g., use of fertilizers containing nutrients is promoted as a cost-effective and fast approach to support on-going efforts of biofortification with micronutrients (Cakmak, 2008, 2009; Choudhary *et al.*, 2010, 2022). Most of the previous studies have indicated that Zn biofortification of potato tubers may best be achieved with foliar Zn application (Waters

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and Sankaran, 2011; White *et al.*, 2012) and only few studies have reported that potatoes could be fortified by soil application of zinc fertilizers (Peter *et al.*, 2017). The chemical interactions of Zn with the soil and the method of fertilizer application have an impact on the availability of Zn fertilizers to plants. In addition, the response to applied Zn differs depending on the type of variety (Peter *et al.*, 2017). This study was done to improve the content of chelated zinc in potato tubers using various methods, application times, and sources of zinc fertilisers because there are very few studies on the agronomic biofortification of potato tubers using these fertilizers.

## MATERIALS AND METHODS

Two field experiments were conducted at ICAR-CPRS, Jalandhar, Punjab (India) during 2015 to 2017 to increase the tuber zinc content using two zinc sources *viz.*, zinc sulphate and Zn-EDTA in Kufri Pukhraj and Kufri Jyoti. Prior to the experiments soil samples were collected to a depth of 30 cm to determine the available nutrient content in soil. The experimental soil was near neutral in pH

(7.3) low in SOC (0.3 to 0.4%) and rich in DTPA-extractable Zn (0.7 to 0.8 mg kg<sup>-1</sup>), Fe (6.8 to 8.1 mg kg<sup>-1</sup>), Mn (7.3-9.4 mg kg<sup>-1</sup>) and copper (0.8-1.0 mg kg<sup>-1</sup>). Available-P in soil was determined by Olsen's method which ranged from 18.9 to 19.8 mg kg<sup>-1</sup>. Available-N in soil was low (205 kg ha<sup>-1</sup>) and other major nutrients available-P and K were in the medium range in soil. The crop was raised by following recommended package of practices. The experiment in the first year was conducted in a drip-irrigated Kufri Pukhraj variety and the treatments included single and split application (25 DAP/earthing up) of zinc fertilizer, foliar application of each source at 45, 60 and 75 days after planting (DAP) and soaking seed tuber in zinc sulphate solution for 30 minutes before planting as described in Table 1. For foliar application, 1000 litres of spray solution was used on per ha basis. No sticker or additive was used for foliar application of Zn. During second year, the experiment was conducted using two varieties (Kufri Pukhraj and Kufri Jyoti) and the treatments included only soil application of zinc at the time of earthing up (25 DAP) and entire dose of Zn was applied (T<sub>1</sub>-

Table 1. Effect of zinc application on tuber and leaf zinc content of Kufri Pukhraj.

| Treatment                                                                                | Zinc concentration in tuber and leaf (mg kg <sup>-1</sup> dry weight basis) |             |             |      | Tuber yield (t ha <sup>-1</sup> ) |
|------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------|-------------|-------------|------|-----------------------------------|
|                                                                                          | Whole tuber                                                                 | Tuber flesh | Tuber peels | Leaf |                                   |
| T <sub>1</sub> -Control                                                                  | 16.8                                                                        | 16.6        | 18.9        | 40.4 | 30.2                              |
| T <sub>2</sub> -Foliar application of Zn (3g zinc sulphate L <sup>-1</sup> )             | 18.4                                                                        | 17.9        | 22.6        | 77.7 | 28.2                              |
| T <sub>3</sub> -Foliar application of Zn (1g Zn-EDTA L <sup>-1</sup> )                   | 17.9                                                                        | 17.5        | 21.5        | 61.6 | 29.4                              |
| T <sub>4</sub> -Single application of Zn (5kg Zn ha <sup>-1</sup> as ZnSO <sub>4</sub> ) | 21.9                                                                        | 21.4        | 28.0        | 51.8 | 30.1                              |
| T <sub>5</sub> -Split application of Zn (5kg Zn ha <sup>-1</sup> as ZnSO <sub>4</sub> )  | 20.1                                                                        | 19.2        | 26.4        | 51.4 | 29.2                              |
| T <sub>6</sub> -Single application of Zn (0.5 kg Zn ha <sup>-1</sup> as Zn-EDTA)         | 19.3                                                                        | 19.1        | 21.3        | 44.9 | 30.4                              |
| T <sub>7</sub> - Split application of Zn (0.5 kg Zn ha <sup>-1</sup> as Zn-EDTA)         | 17.4                                                                        | 17.2        | 19.9        | 43.6 | 28.9                              |
| T <sub>8</sub> -Single application of Zn (1kg Zn ha <sup>-1</sup> as Zn-EDTA)            | 19.7                                                                        | 19.3        | 23.8        | 46.1 | 30.8                              |
| T <sub>9</sub> -Split application of Zn (1kg Zn ha <sup>-1</sup> as Zn-EDTA)             | 18.7                                                                        | 18.3        | 22.4        | 45.9 | 29.6                              |
| T <sub>10</sub> - Soaking of seed tuber (2g ZnSO <sub>4</sub> L <sup>-1</sup> )          | 18.5                                                                        | 18.0        | 22.9        | 52.5 | 30.1                              |
| LSD ( <i>p</i> =0.05)                                                                    | 2.5                                                                         | *NS         | 3.2         | 6.3  | NS                                |

\*NS implies non-significant

Control; T<sub>2</sub>- ZnSO<sub>4</sub> (5 kg Zn ha<sup>-1</sup>), T<sub>3</sub>- ZnSO<sub>4</sub> (10 kg Zn ha<sup>-1</sup>) , T<sub>4</sub>- Zn-EDTA (1 kg Zn ha<sup>-1</sup>) and T<sub>5</sub>- Zn-EDTA (2 kg Zn ha<sup>-1</sup>). Leaf and tuber samples were collected from the four middle rows of each plot to avoid border effects. Tubers were peeled single handily to ensure the uniformity of peeling with a food grade stainless steel peeler. Leaf samples were collected 15 days after last Zn application during the experiment i.e. at 90 DAP in the first year and 40 DAP during the second year. Tuber and leaf samples were washed in pure nitric acid followed by distilled water, peeled and oven-dried at 70°C, ground in stainless steel grinder, digested with nitric and perchloric acid for nutrient analysis and the data were statistically analysed using randomized block design.

## RESULTS AND DISCUSSION

The present study showed that fertilizer application practices could enhance Zn content in potato tubers. Only data on zinc concentration is presented here, since the concentration of other nutrients were not affected significantly by any of the zinc treatments in this study. For first year, a single soil application of 5 kg Zn ha<sup>-1</sup> as ZnSO<sub>4</sub> increased its concentration by 30% (5.0 mg kg<sup>-1</sup> on dry wet basis) followed by split application of ZnSO<sub>4</sub> (19.6%) and single application of 1kg Zn as Zn-EDTA (17.6%) over control in whole tubers (unpeeled tubers) (Table 1). A single soil application 5kg Zn (zinc sulphate) increased its concentration by 9.0 mg kg<sup>-1</sup> (dry weight basis) in tuber peels which was 1.5 times higher than control (no external zinc application). Differences between single and split applications of Zn were not significant. Other treatments viz. soil application of 5 kg Zn as ZnSO<sub>4</sub> (split application); 1 kg Zn as Zn-EDTA (single or split application); three foliar applications of zinc (zinc sulphate) and soaking of seed tubers with ZnSO<sub>4</sub> also increased the

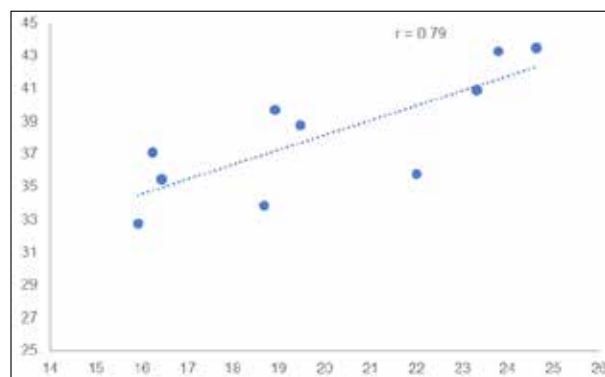
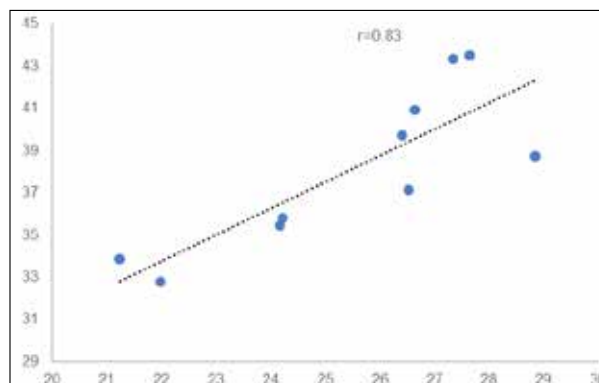
Zn concentration in tuber peels (Table 1). However, the increase was less as compared to single soil application of zinc sulphate. Split application of zinc sulphate also increased the Zn concentration significantly. Single application of 5 kg zinc as zinc sulphate at 25 DAP also increased its concentration by 5.2 mg kg<sup>-1</sup> over control treatment (Table 1), the increase, however, was not statistically significant. Foliar applications of zinc, seed tuber soaking, and 5kg Zn ha<sup>-1</sup> increased the leaf zinc content significantly (Table 1). According to Peter et al. (2016), foliar and soil applications of Zn fertilizers increased the content of Zn in both the meat and skin of tubers. In our experiments, foliar application of zinc sulphate considerably enhanced the amount of zinc in tuber peels; however, foliar application of zinc in the form of Zn-EDTA only resulted in a non-significant increase, which may be related to the lower rate of Zn-EDTA used in our study. Although every preventative measure was taken to wash the leaves before analysis, it is important to carefully interpret the increased leaf Zn concentration caused by foliar Zn fertilizer application because the concentrations that were reported may have included foliage applied Zn deposited that had not yet passed the plant cuticle.

During the second year, soil application of Zn applied either ZnSO<sub>4</sub> or Zn-EDTA significantly increased its concentration in both peeled and unpeeled tubers in both varieties (Table 2). In tuber flesh highest average increase of 4.4mg kg<sup>-1</sup> Zn (25.7%) was with the application of 2 kg zinc as Zn-EDTA which was statistically at par with 10.0 kg Zn applied as ZnSO<sub>4</sub> (24.9%). At lower rate of application, 1kg chelated Zn (Zn-EDTA) increased the zinc content by 14.2% compared to 11.1% increase by 5kg zinc as zinc sulphate. In unpeeled tubers the highest increase of 6.4mg kg<sup>-1</sup> Zn (29.9%) was

**Table 2.** Effect of zinc levels on tuber and leaf zinc content (mg kg<sup>-1</sup> dry weight basis) in Kufri Pukhraj and Kufri Jyoti

| Treatments                                       | Tuber flesh   |             |      | Whole tuber          |             |      | Leaf          |             |      | Tuber yield (t ha <sup>-1</sup> ) |             |      |
|--------------------------------------------------|---------------|-------------|------|----------------------|-------------|------|---------------|-------------|------|-----------------------------------|-------------|------|
|                                                  | Kufri Pukhraj | Kufri Jyoti | Mean | Kufri Pukhraj        | Kufri Jyoti | Mean | Kufri Pukhraj | Kufri Jyoti | Mean | Kufri Pukhraj                     | Kufri Jyoti | Mean |
| Control (no Zn applied)                          | 15.9          | 18.6        | 17.3 | 21.9                 | 21.2        | 21.6 | 32.7          | 33.8        | 33.3 | 27.3                              | 22.7        | 25.0 |
| 5 kg Zn ha <sup>-1</sup> (as ZnSO <sub>4</sub> ) | 16.4          | 22.0        | 19.2 | 24.1                 | 24.2        | 24.1 | 35.4          | 35.8        | 35.6 | 28.8                              | 25.2        | 27.0 |
| 10 kg Zn ha <sup>-1</sup> (ZnSO <sub>4</sub> )   | 19.4          | 23.7        | 21.6 | 28.8                 | 27.3        | 28.0 | 38.7          | 43.3        | 41.0 | 29.0                              | 25.2        | 27.1 |
| 1 kg Zn ha <sup>-1</sup> (Zn-EDTA)               | 16.2          | 23.3        | 19.7 | 26.5                 | 26.6        | 26.5 | 37.1          | 40.9        | 39.0 | 28.1                              | 23.4        | 25.8 |
| 2 kg Zn ha <sup>-1</sup> (Zn-EDTA)               | 18.9          | 24.6        | 21.7 | 26.4                 | 27.6        | 27.0 | 39.7          | 43.5        | 41.6 | 29.2                              | 25.4        | 27.3 |
| Mean                                             | 17.3          | 22.4        |      | 25.5                 | 25.4        |      | 36.7          | 39.4        |      | 28.5                              | 24.4        |      |
| LSD ( <i>p</i> =0.05)                            |               |             |      |                      |             |      |               |             |      |                                   |             |      |
| Zn levels                                        |               | 1.3         |      |                      | 2.5         |      |               | 1.6         |      |                                   | NS          |      |
| Variety                                          |               | 0.8         |      | NS (non-significant) |             |      |               | 1.0         |      |                                   | 1.2         |      |
| Zn level×variety                                 |               | 1.9         |      |                      |             |      |               | NS          |      |                                   | NS          |      |

recorded with the application of 10kg Zn as ZnSO<sub>4</sub> which was statistically at par with 2 kg zinc applied as Zn-EDTA. Zinc sulphate and Zn-EDTA also significantly increased the leaf Zn concentration. A positive correlation (Fig. 1 and 2) was observed between Zn concentration in leaf and Zn concentration in peeled (*r*=0.79) and unpeeled tubers (*r*=0.83). On application rate basis, compared to ZnSO<sub>4</sub> five times lesser amount of Zn (as Zn-EDTA) was needed for equivalent increase in Zn content of potato tubers. Comparable accumulation of Zn in tuber by low rates of Zn-EDTA is attributed to its better mobility into the soil compared to inorganic Zn salt (ZnSO<sub>4</sub>) which may be positionally less

**Fig. 1.** Relationship between leaf and tuber flesh Zn content**Fig. 2.** Relationship between leaf and unpeeled tuber Zn content

available to plants (Boawn, 1973; Pooniya *et al.*, 2019). Most of the previous studies have indicated that Zn biofortification of potato tubers may best be achieved with foliar Zn application (Waters and Sankaran, 2011; White and Broadley, 2011; White *et al.*, 2012), however, our study revealed that apart from foliar application, soil application of zinc fertilisers (chelated or inorganic) is also effective as has been reported in few studies conducted elsewhere (Peter *et al.*, 2016).

## CONCLUSION

Until Zn rich varieties are developed, soil application of zinc fertilizers during the initial crop growth stage, as revealed by present

study can be adopted as a simple strategy for increasing its content in tubers to fight Zn malnutrition and support ongoing efforts on biofortification.

## CONFLICTS OF INTEREST

The authors confirm that this manuscript has no conflicts of interest

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# SIMPLE SEQUENCE REPEAT (SSR) ANALYSIS OF MULTI-COLOURED POTATO HYBRID PROGENIES

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**ABSTRACT:** The aim of this study was to analyze multi-coloured flesh potato hybrids using simple sequence repeat (SSR) markers and identify diagnostic SSRs for genetic fidelity purpose. The parents MP/4-816 (female) and CP4242 (male) were hybridized and 108 progenies (MSP/17-136 to MSP/17-243) were produced. The 110 genotypes (2 parents and 108 progenies) were analysed by 59 known potato SSR markers. Of which, only one marker STI0003 (PIC: 0.84) was identified or diagnostic purpose, which clearly distinguished the hybrid progenies. Allelic profile of STI0003 showed total eight alleles (118, 122, 125, 130, 139, 145, 149 and 152 bp), of which distinct alleles were 118, 130 and 149 bp in MP/4-816, and 130, 149 and 152 bp in CP 4242, and their progenies contained 2 to 7 alleles. The study suggests that STI0003 is a diagnostic marker for further characterization of these multi-coloured potato hybrids.

**KEYWORDS** Multi-colour potato, hybrids, SSR, identification

## INTRODUCTION

Potato is a wholesome food in term of its high nutritive value, energy, dry matter per unit area and time compared to cereals, and its capacity to ensure food and nutritional security of the world (Chakrabarti *et al.*, 2017). The Indian potato breeding has been largely focussed on developing white-fleshed varieties having biotic and abiotic stress tolerance/resistance quality and other desirable tuber traits. Mostly red-skinned potatoes are preferred in eastern part of the country like Bihar, West-Bengal and North-East, whereas white and light yellow fleshed varieties are preferred all over the country. On the other hand, multi-coloured potato varieties with red/purple/yellow flesh colours has several health benefits on account of rich source of antioxidants (anthocyanins & carotenoids) and micronutrients like Fe and Zn (Luthra *et al.*, 2018). Hence, now focus has been reoriented at the institute to

develop coloured potato varieties, which can benefit the people and ensure both food and nutritional security.

Cultivated and wild/semi-cultivated species of potato are rich source of genetic resources (Chakrabarti *et al.*, 2017). Hence, there is enough opportunity to develop coloured potato varieties in near future. While developing varieties, it is also important to ensure genetic fidelity of genotypes by molecular markers like RAPD, ISSR, SSR, ALFP etc, so that variety can be identified in future. A large number of markers have been applied in potato for molecular characterization of potato species (Ghislain *et al.*, 2009), somatic hybrids (Chandel *et al.*, 2015), varietal identification (Tiwari *et al.*, 2018), wild species (Tiwari *et al.*, 2019) and genetic diversity (Provan *et al.*, 1996) so on. Hence, the aim of this study was to develop diagnostic SSR marker for identification of potato clones with multi-coloured flesh tubers.

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## MATERIAL AND METHODS

In the present investigation, indigenous advanced stage hybrid MP/4-816 (female parent) and exotic germplasm accession CP4242-Bora Valley (male parent) were hybridized at ICAR-CPRI, Regional Station, Modipuram, Meerut, UP during 2015-16 and seedlings raising (2016-17) and  $F_1C_1$  stage (2017-18) were grown at ICAR-CPRI, Regional Station, Modipuram, Meerut. Phenotyping data of breeding materials were recorded based on the standard procedures described by Luthra et al. (2018) and reported here. The 108 progenies (MSP/17-136 to MSP/17-243) along with parents MP/4-816 and CP4242 were selected for DNA analysis. Leaf samples of 110 genotypes (2 parents and 108 progenies) were analysed using 59 simple sequence repeat (SSR) markers. The annealing temperature was 55°C for the SSR markers (STG0016, STM0001, STM0003, STM0004, STM0007, STM0010, STM0011, STM0013, STM0015, STM0017, STM0019, STM0023, STM0031, STM0032, STM0037, STM0046, STM1001, STM1003, STM1007, STM1024, STM1036, STM1041, STM1043, STM1046, STM1052, STM1057, STM1058, STM1064, STM1069, STM1097, STM2002, STM2003, STM2004, STM2005, STM2020, STM2021, STM2023, STM2026, STM3003, STM3012, STM3018, STM51217), except some STG0025 (56°C), STI0001 (60°C), STI0003 (60°C), STI0004 (60°C), STI0012 (56°C), STI0014 (54°C), STI0030 (58°C), STI0032 (61°C), STI0033 (61°C), STG0001 (58°C), STG0010 (60°C), STM1053 (53°C), STM1104 (53°C), STM1106 (51°C), STM5114 (60°C), STM5121 (50°C) and STPoAC58 (57°C) (Provan *et al.*, 1996; Ghislain *et al.*, 2009). Initially SSR markers were selected for profiling of total 110 samples using 59 SSR markers. Further, only one marker could be selected for Genetic Analyzer analysis based on the two or more clear bands on the gel among the

lines. Other markers showed either one or non-scorable and overlapping bands on the gel, hence not carried further. DNA isolation was performed using DNeasy Plant Mini kit (Qiagen, the Netherlands) and quality was checked on agarose gel (1%) and NanoDrop (Thermo Fisher Scientific, USA). Polymerase chain reaction (PCR) included total of 10 µl reaction mix which included 100 ng DNA, 1 µl (10 pM) each primer (forward and reverse), 1 U Taq polymerase, PCR buffer with 2.5 mM  $MgCl_2$  and 200 µM dNTP and Milli-Q water (Qiagen). The PCR cycles included denaturation at 95°C/5 min; 35 cycles of 94 °C/45 sec, annealing (except above) at 55 °C /45 sec, and 72 °C for 1 min; and extension at 72 °C/7 min in GeneAmp PCR System (Applied Biosystems, CA, USA). The amplified PCR products were resolved on high resolution agarose gel (3%). Of which only selected SSR markers were synthesized with FAM labelled and PCR amplified. The amplified PCR products were analysed with a 500-bp 'GS 500 ROX' standard on '3500 Genetic Analyzer' using GeneMapper® Software Version 4.1 (Applied Biosystems, CA, USA). SSR fragments were recorded from the Genetic Analyzer based on the repeat motifs, whereas on gel it was scored by comparing with the known DNA ladder. PCR reactions were repeated twice and only reproducible and distinct SSR markers were selected for further analysis. Scoring was done on the basis of presence (1) or absence (0) of SSR fragments. Cluster analysis was performed with unweighted Neighbour Joining using the DARwin software using bootstrap value 100.

## RESULTS AND DISCUSSION

The tubers phenotypes of the 108 progenies of cross MP/4-816 × CP4242 indicated wide variation for tuber skin and flesh colour as compared to parents MP/4-

816 (light yellow ovoid tubers with shallow eyes and light yellow flesh) and CP4242 (purple oblong tubers with shallow eyes and purple flesh (**Fig. 1**). The tuber skin colour of the progenies varied from pink, purple to yellow and flesh colour varied from cream, yellow, pink to purple with contrasting secondary colour of pink and purple variegation different than both the parents. The tuber shape of the progenies also segregated from ovoid to oblong. However, eyes depth (shallow or fleet) of the progenies was almost similar to both the parents (shallow eyes) (Luthra et al. 2018).

A total of 59 SSR markers were analysed in all 110 samples (2 parents and 108 progenies). The PCR products were checked on high-resolution agarose gel (3%) to visualize polymorphic bands in the parents and

progenies. However, only one SSR marker (STI0003) was identified as diagnostic SSR marker for the identification of the multi-colour fleshed progenies. The SSR profile of STI0003 (PIC: 0.84) showed polymorphism in 110 genotypes (**Fig. 2**). Further, SSR profile of FAM dye-labelled STI0003 marker showed good polymorphism using '3500 Genetic Analyzer' and the distribution of alleles in the parents and progenies is depicted in **Fig. 3** and summarised in **Tables 1** and **2**. The allelic profiles of STI0003 marker showed total eight alleles (118, 122, 125, 130, 139, 145, 149 and 152 bp) in the 110 genotypes (**Table 2**). Of which, very distinct STI0003 alleles in parent MP/4-816 were 118, 130 and 149 bp; whereas alleles in CP 4242 were 130, 149 and 152 bp, and progenies contained 2 to 7 alleles (e.g. MSP/17-13: 130 and 149 bp).



Fig. 1. Tuber traits of parents (MP/4-816 & CP4242) and progenies (MSP/17-147 & MSP/17-212)

Table 1. Allelic profile of diagnostic SSR marker (STI0003) for identification of multi-coloured fleshed potato hybrids

| SSR marker | SSR motif | Sequence (5'→3')                                  | Ta (°C) | Allele size (bp) | No. of genotypes having alleles | Allele frequency | PIC  |
|------------|-----------|---------------------------------------------------|---------|------------------|---------------------------------|------------------|------|
| STI0003    | (ACC)n    | F: ACCATCCACCATGTCAATGC<br>R: CTCATGGATGGTGCATTGG | 60      | 118              | 44                              | 0.095            | 0.84 |
|            |           |                                                   |         | 122              | 29                              | 0.062            |      |
|            |           |                                                   |         | 125              | 60                              | 0.129            |      |
|            |           |                                                   |         | 130              | 105                             | 0.227            |      |
|            |           |                                                   |         | 139              | 34                              | 0.073            |      |
|            |           |                                                   |         | 145              | 30                              | 0.064            |      |
|            |           |                                                   |         | 149              | 86                              | 0.186            |      |
|            |           |                                                   |         | 152              | 74                              | 0.160            |      |
| Total      |           |                                                   |         |                  | 460                             | 1                |      |

Note: Allele frequency=Number of allele counts in genotypes present/Total number of allele counts in all genotypes i.e. 460 (e.g. 44/460 = 0.095 so on)

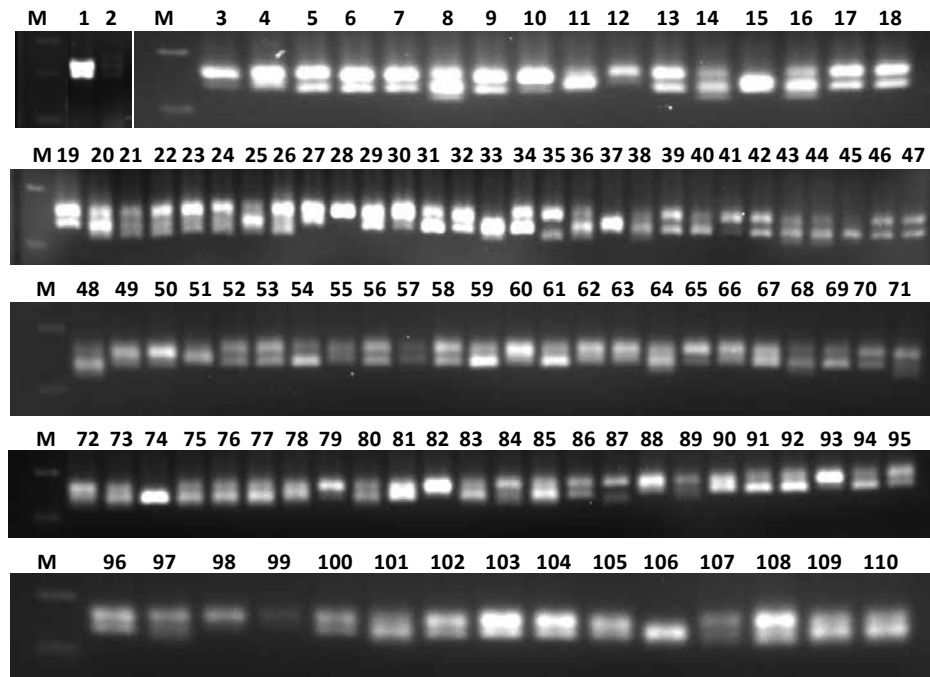


Fig. 2. Gel profile of 110 genotypes (2 parents and 108 progenies) analysed by SSR marker (STI0003). Gel images: M=DNA ladder 50 bp; 1=MP/4-816; 2=CP4242; 3-110: MSP/17-136 to MSP/17-243.

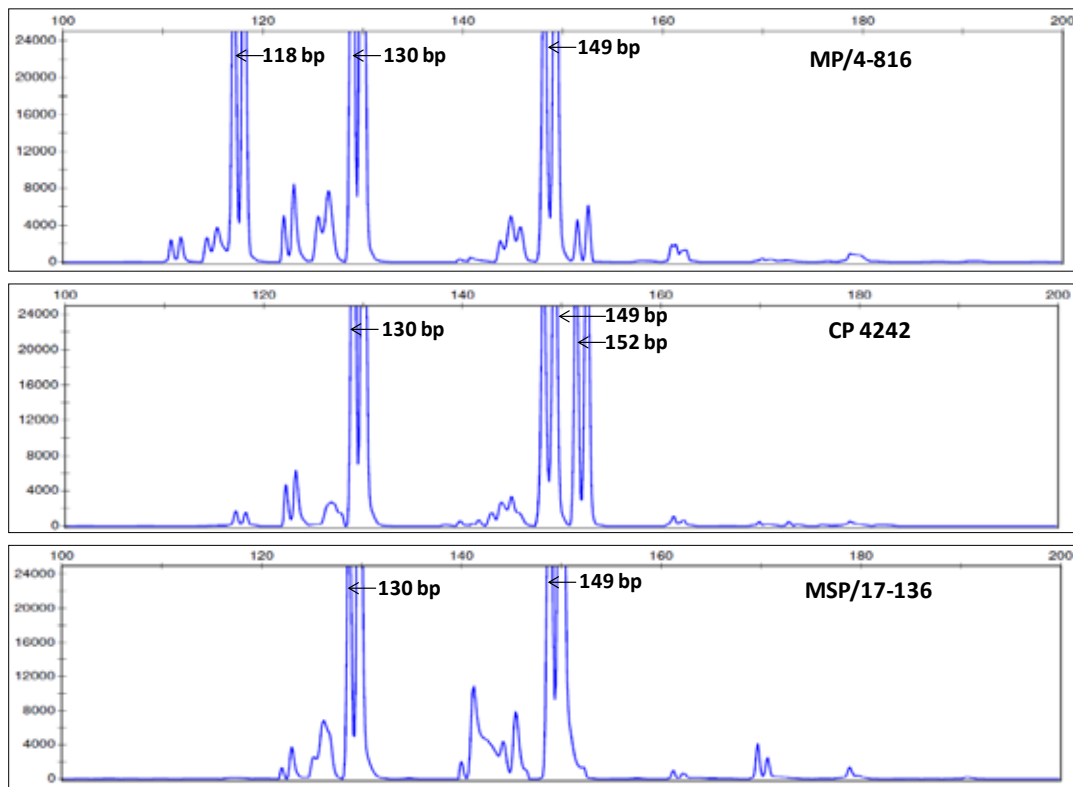


Fig. 3. Molecular profile of potato progenies by FAM labelled SSR marker STI0003 using '3500 Genetic Analyzer' (ABI). Parents: MP/4-816 and CP4242; and their progeny MSP/17-136.

**Table 2. SSR allelic profiles of the parents and progenies for multi-coloured flesh potatoes**

| Sr. No.                        | Sample     | SSR (STI0003) allele size (bp) |     |     |     |     |     |     |     | Allele # |
|--------------------------------|------------|--------------------------------|-----|-----|-----|-----|-----|-----|-----|----------|
|                                |            | 118                            | 122 | 125 | 130 | 139 | 145 | 149 | 152 |          |
| Parents                        |            |                                |     |     |     |     |     |     |     |          |
| 1.                             | MP/4-816   | 1                              | 1   | 1   | 1   | 1   | 1   | 1   | 1   | 8        |
| 2.                             | CP 4242    | 0                              | 1   | 1   | 1   | 0   | 0   | 1   | 1   | 5        |
| Progenies (MP/4-816 × CP 4242) |            |                                |     |     |     |     |     |     |     |          |
| 3.                             | MSP/17-136 | 0                              | 1   | 1   | 1   | 1   | 1   | 1   | 0   | 6        |
| 4.                             | MSP/17-137 | 0                              | 0   | 1   | 1   | 1   | 1   | 1   | 1   | 6        |
| 5.                             | MSP/17-138 | 0                              | 1   | 1   | 1   | 0   | 1   | 1   | 1   | 6        |
| 6.                             | MSP/17-139 | 0                              | 1   | 1   | 1   | 1   | 1   | 1   | 0   | 6        |
| 7.                             | MSP/17-140 | 0                              | 1   | 1   | 1   | 1   | 1   | 1   | 0   | 6        |
| 8.                             | MSP/17-141 | 1                              | 0   | 1   | 1   | 0   | 0   | 1   | 1   | 5        |
| 9.                             | MSP/17-142 | 0                              | 1   | 1   | 1   | 1   | 1   | 1   | 0   | 6        |
| 10.                            | MSP/17-143 | 0                              | 1   | 1   | 1   | 1   | 1   | 1   | 1   | 7        |
| 11.                            | MSP/17-144 | 0                              | 0   | 1   | 1   | 1   | 1   | 0   | 1   | 5        |
| 12.                            | MSP/17-145 | 0                              | 0   | 0   | 1   | 1   | 1   | 1   | 1   | 5        |
| 13.                            | MSP/17-146 | 0                              | 1   | 1   | 1   | 0   | 1   | 1   | 1   | 6        |
| 14.                            | MSP/17-147 | 1                              | 1   | 1   | 1   | 0   | 0   | 1   | 1   | 6        |
| 15.                            | MSP/17-148 | 0                              | 1   | 1   | 1   | 1   | 0   | 0   | 0   | 4        |
| 16.                            | MSP/17-149 | 1                              | 1   | 1   | 1   | 0   | 0   | 1   | 1   | 6        |
| 17.                            | MSP/17-150 | 0                              | 1   | 1   | 1   | 0   | 1   | 1   | 1   | 6        |
| 18.                            | MSP/17-151 | 0                              | 1   | 1   | 1   | 0   | 1   | 1   | 1   | 6        |
| 19.                            | MSP/17-152 | 0                              | 1   | 1   | 1   | 1   | 1   | 1   | 0   | 6        |
| 20.                            | MSP/17-153 | 1                              | 0   | 1   | 1   | 0   | 0   | 0   | 1   | 4        |
| 21.                            | MSP/17-154 | 0                              | 1   | 1   | 1   | 1   | 1   | 1   | 0   | 6        |
| 22.                            | MSP/17-155 | 1                              | 1   | 1   | 1   | 0   | 1   | 1   | 1   | 7        |
| 23.                            | MSP/17-156 | 1                              | 1   | 1   | 1   | 1   | 1   | 1   | 0   | 7        |
| 24.                            | MSP/17-157 | 1                              | 0   | 1   | 1   | 0   | 1   | 1   | 1   | 6        |
| 25.                            | MSP/17-158 | 1                              | 1   | 1   | 1   | 0   | 0   | 1   | 1   | 6        |
| 26.                            | MSP/17-159 | 1                              | 1   | 1   | 1   | 0   | 1   | 1   | 1   | 7        |
| 27.                            | MSP/17-160 | 0                              | 1   | 1   | 1   | 1   | 1   | 1   | 1   | 7        |
| 28.                            | MSP/17-161 | 0                              | 0   | 0   | 0   | 1   | 1   | 1   | 1   | 4        |
| 29.                            | MSP/17-162 | 0                              | 1   | 1   | 1   | 1   | 1   | 1   | 0   | 6        |
| 30.                            | MSP/17-163 | 0                              | 0   | 0   | 1   | 1   | 1   | 1   | 0   | 4        |
| 31.                            | MSP/17-164 | 0                              | 0   | 1   | 1   | 0   | 0   | 0   | 1   | 3        |
| 32.                            | MSP/17-165 | 0                              | 0   | 0   | 1   | 0   | 0   | 1   | 0   | 2        |
| 33.                            | MSP/17-166 | 1                              | 1   | 1   | 1   | 0   | 0   | 0   | 0   | 4        |
| 34.                            | MSP/17-167 | 0                              | 1   | 1   | 1   | 0   | 0   | 0   | 1   | 4        |
| 35.                            | MSP/17-168 | 1                              | 0   | 0   | 0   | 0   | 1   | 1   | 1   | 4        |
| 36.                            | MSP/17-169 | 1                              | 1   | 1   | 1   | 0   | 0   | 1   | 1   | 6        |

| Sr. No. | Sample     | SSR (STI0003) allele size (bp) |     |     |     |     |     |     |     | Allele # |
|---------|------------|--------------------------------|-----|-----|-----|-----|-----|-----|-----|----------|
|         |            | 118                            | 122 | 125 | 130 | 139 | 145 | 149 | 152 |          |
| 37.     | MSP/17-170 | 0                              | 1   | 1   | 1   | 1   | 0   | 0   | 0   | 4        |
| 38.     | MSP/17-171 | 1                              | 1   | 1   | 1   | 0   | 1   | 1   | 0   | 6        |
| 39.     | MSP/17-172 | 1                              | 1   | 1   | 1   | 0   | 1   | 1   | 1   | 7        |
| 40.     | MSP/17-173 | 0                              | 1   | 0   | 1   | 1   | 0   | 1   | 1   | 5        |
| 41.     | MSP/17-174 | 0                              | 0   | 0   | 1   | 0   | 0   | 1   | 1   | 3        |
| 42.     | MSP/17-175 | 0                              | 0   | 0   | 1   | 0   | 0   | 1   | 1   | 3        |
| 43.     | MSP/17-176 | 1                              | 0   | 0   | 1   | 0   | 0   | 1   | 0   | 3        |
| 44.     | MSP/17-177 | 1                              | 0   | 0   | 1   | 0   | 0   | 0   | 1   | 3        |
| 45.     | MSP/17-178 | 0                              | 0   | 1   | 1   | 0   | 0   | 1   | 0   | 3        |
| 46.     | MSP/17-179 | 1                              | 0   | 1   | 1   | 0   | 0   | 1   | 1   | 5        |
| 47.     | MSP/17-180 | 0                              | 0   | 0   | 1   | 0   | 0   | 1   | 1   | 3        |
| 48.     | MSP/17-181 | 1                              | 0   | 0   | 1   | 0   | 0   | 0   | 1   | 3        |
| 49.     | MSP/17-182 | 0                              | 0   | 0   | 1   | 1   | 1   | 1   | 1   | 5        |
| 50.     | MSP/17-183 | 0                              | 0   | 0   | 1   | 0   | 1   | 1   | 0   | 3        |
| 51.     | MSP/17-184 | 0                              | 0   | 0   | 1   | 1   | 0   | 0   | 1   | 3        |
| 52.     | MSP/17-185 | 0                              | 0   | 0   | 1   | 0   | 0   | 1   | 1   | 3        |
| 53.     | MSP/17-186 | 0                              | 0   | 0   | 1   | 0   | 0   | 1   | 1   | 3        |
| 54.     | MSP/17-187 | 0                              | 0   | 1   | 1   | 0   | 0   | 1   | 1   | 4        |
| 55.     | MSP/17-188 | 0                              | 0   | 0   | 1   | 1   | 0   | 1   | 1   | 4        |
| 56.     | MSP/17-189 | 0                              | 0   | 1   | 1   | 0   | 0   | 1   | 1   | 4        |
| 57.     | MSP/17-190 | 1                              | 0   | 0   | 1   | 0   | 0   | 1   | 0   | 3        |
| 58.     | MSP/17-191 | 0                              | 0   | 0   | 1   | 0   | 0   | 1   | 1   | 3        |
| 59.     | MSP/17-192 | 0                              | 0   | 1   | 1   | 0   | 0   | 1   | 0   | 3        |
| 60.     | MSP/17-193 | 0                              | 0   | 0   | 1   | 1   | 0   | 1   | 0   | 3        |
| 61.     | MSP/17-194 | 0                              | 0   | 1   | 1   | 0   | 0   | 1   | 0   | 3        |
| 62.     | MSP/17-195 | 0                              | 0   | 0   | 1   | 1   | 0   | 1   | 1   | 4        |
| 63.     | MSP/17-196 | 0                              | 0   | 0   | 1   | 1   | 0   | 1   | 1   | 4        |
| 64.     | MSP/17-197 | 1                              | 0   | 1   | 1   | 0   | 0   | 1   | 0   | 4        |
| 65.     | MSP/17-198 | 0                              | 0   | 0   | 1   | 0   | 0   | 1   | 1   | 3        |
| 66.     | MSP/17-199 | 0                              | 0   | 0   | 1   | 1   | 0   | 1   | 1   | 4        |
| 67.     | MSP/17-200 | 0                              | 0   | 1   | 1   | 1   | 0   | 1   | 0   | 4        |
| 68.     | MSP/17-201 | 1                              | 0   | 0   | 1   | 0   | 0   | 0   | 1   | 3        |
| 69.     | MSP/17-202 | 0                              | 0   | 1   | 1   | 0   | 0   | 1   | 0   | 3        |
| 70.     | MSP/17-203 | 0                              | 0   | 0   | 1   | 0   | 0   | 1   | 0   | 2        |
| 71.     | MSP/17-204 | 1                              | 0   | 0   | 1   | 0   | 0   | 1   | 0   | 3        |
| 72.     | MSP/17-205 | 1                              | 0   | 0   | 1   | 1   | 0   | 1   | 1   | 5        |
| 73.     | MSP/17-206 | 1                              | 0   | 0   | 1   | 0   | 0   | 1   | 0   | 3        |
| 74.     | MSP/17-207 | 0                              | 0   | 1   | 1   | 0   | 0   | 0   | 0   | 2        |
| 75.     | MSP/17-208 | 1                              | 0   | 0   | 1   | 0   | 0   | 0   | 1   | 3        |

| Sr. No.  | Sample     | SSR (STI0003) allele size (bp) |     |     |     |     |     |     |     | Allele # |
|----------|------------|--------------------------------|-----|-----|-----|-----|-----|-----|-----|----------|
|          |            | 118                            | 122 | 125 | 130 | 139 | 145 | 149 | 152 |          |
| 76.      | MSP/17-209 | 1                              | 0   | 0   | 1   | 0   | 0   | 0   | 1   | 3        |
| 77.      | MSP/17-210 | 1                              | 0   | 1   | 1   | 0   | 0   | 0   | 1   | 4        |
| 78.      | MSP/17-211 | 1                              | 0   | 0   | 1   | 1   | 0   | 1   | 1   | 5        |
| 79.      | MSP/17-212 | 0                              | 0   | 0   | 1   | 1   | 0   | 1   | 1   | 4        |
| 80.      | MSP/17-213 | 1                              | 0   | 1   | 1   | 0   | 0   | 1   | 1   | 5        |
| 81.      | MSP/17-214 | 0                              | 0   | 1   | 1   | 1   | 0   | 1   | 0   | 4        |
| 82.      | MSP/17-215 | 0                              | 0   | 0   | 0   | 1   | 1   | 1   | 0   | 3        |
| 83.      | MSP/17-216 | 1                              | 0   | 1   | 1   | 0   | 0   | 1   | 1   | 5        |
| 84.      | MSP/17-217 | 1                              | 0   | 0   | 1   | 0   | 0   | 1   | 1   | 4        |
| 85.      | MSP/17-218 | 1                              | 0   | 1   | 1   | 0   | 0   | 0   | 1   | 4        |
| 86.      | MSP/17-219 | 0                              | 0   | 1   | 1   | 0   | 0   | 1   | 1   | 4        |
| 87.      | MSP/17-220 | 1                              | 0   | 0   | 0   | 0   | 0   | 1   | 1   | 3        |
| 88.      | MSP/17-221 | 1                              | 0   | 0   | 0   | 0   | 0   | 0   | 1   | 2        |
| 89.      | MSP/17-222 | 1                              | 0   | 0   | 1   | 0   | 0   | 1   | 0   | 3        |
| 90.      | MSP/17-223 | 0                              | 0   | 1   | 1   | 1   | 0   | 1   | 0   | 4        |
| 91.      | MSP/17-224 | 0                              | 0   | 1   | 1   | 0   | 0   | 0   | 1   | 3        |
| 92.      | MSP/17-225 | 0                              | 0   | 1   | 1   | 0   | 0   | 0   | 1   | 3        |
| 93.      | MSP/17-226 | 0                              | 0   | 0   | 1   | 0   | 1   | 1   | 0   | 3        |
| 94.      | MSP/17-227 | 0                              | 0   | 1   | 1   | 0   | 0   | 0   | 1   | 3        |
| 95.      | MSP/17-228 | 0                              | 0   | 0   | 1   | 0   | 0   | 1   | 1   | 3        |
| 96.      | MSP/17-229 | 0                              | 0   | 1   | 1   | 0   | 0   | 1   | 1   | 4        |
| 97.      | MSP/17-230 | 1                              | 0   | 0   | 1   | 0   | 0   | 1   | 1   | 4        |
| 98.      | MSP/17-231 | 0                              | 0   | 0   | 1   | 0   | 0   | 1   | 1   | 3        |
| 99.      | MSP/17-232 | 0                              | 0   | 0   | 1   | 0   | 0   | 1   | 1   | 3        |
| 100.     | MSP/17-233 | 0                              | 0   | 0   | 1   | 1   | 0   | 1   | 0   | 3        |
| 101.     | MSP/17-234 | 1                              | 0   | 0   | 1   | 0   | 0   | 0   | 1   | 3        |
| 102.     | MSP/17-235 | 0                              | 0   | 0   | 1   | 0   | 0   | 1   | 1   | 3        |
| 103.     | MSP/17-236 | 0                              | 0   | 1   | 1   | 0   | 0   | 1   | 1   | 4        |
| 104.     | MSP/17-237 | 0                              | 0   | 1   | 1   | 0   | 0   | 1   | 1   | 4        |
| 105.     | MSP/17-238 | 1                              | 0   | 1   | 1   | 0   | 0   | 1   | 0   | 4        |
| 106.     | MSP/17-239 | 1                              | 0   | 1   | 1   | 0   | 0   | 0   | 0   | 3        |
| 107.     | MSP/17-240 | 1                              | 0   | 0   | 1   | 0   | 0   | 1   | 1   | 4        |
| 108.     | MSP/17-241 | 1                              | 0   | 0   | 1   | 0   | 0   | 1   | 1   | 4        |
| 109.     | MSP/17-242 | 1                              | 0   | 1   | 1   | 0   | 0   | 0   | 1   | 4        |
| 110.     | MSP/17-243 | 1                              | 0   | 0   | 1   | 0   | 0   | 0   | 1   | 3        |
| Allele # |            | 44                             | 29  | 60  | 105 | 34  | 30  | 86  | 74  | 462      |

Note: Presence: 1; Absence: 0

In terms of allelic richness, allele size of 130 bp was found in maximum (105) genotypes followed by 149 bp (86) and 152 bp (74). Cluster analysis using STI0003 marker data showed genetic distinctness in 110 genotypes is depicted in **Fig. 4**. Other 58 markers were either very faint or monomorphic or non-scorable amplification or non-amplification type in our tested samples (data not reported).

SSR markers have been used in potato for various applications like genetic diversity (Provan *et al.*, 1996; Ghislain *et al.*, 2009), varietal characterization (Tiwari *et al.*, 2018), wild species (Tiwari *et al.*, 2019), core collection characterization (Tiwari *et al.*, 2013). Our results are in agreement with allelic profile of this marker (Tiwari *et al.* 2013, 2018, 2019). Interestingly, this marker (STI0003) profile can be used for identification of varieties developed from this progenies. Many of the advanced stage hybrids are in pipeline to develop new

varieties in future. Studies showed that SSR has excellent discriminatory power for molecular characterization of potato species, land races characterization (Provan *et al.*, 1996). SSR profiles in terms of allele size and number could be variable due to scoring technology used in the study. Earlier, we have used SSR markers for characterization of somatic hybrids (Chandel *et al.*, 2015), varietal identification (Tiwari *et al.*, 2018), wild species (Tiwari *et al.*, 2019). This study identifies STI0003 as diagnostic marker for identification of parents MP/4-816 and CP4242, and their segregating progenies.

## CONCLUSION

This investigation identified SSR marker (STI0003) for characterization and identification of potato clones developed by crossing MP/4-816 (118, 130 and 149 bp) and CP4242 (130, 149 and 152 bp). Nevertheless, future study would be required to investigate genetic stability and linked markers with the flesh colour of the potato genotypes.

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## CONFLICTS OF INTEREST

The authors confirm that this manuscript has no conflicts of interest

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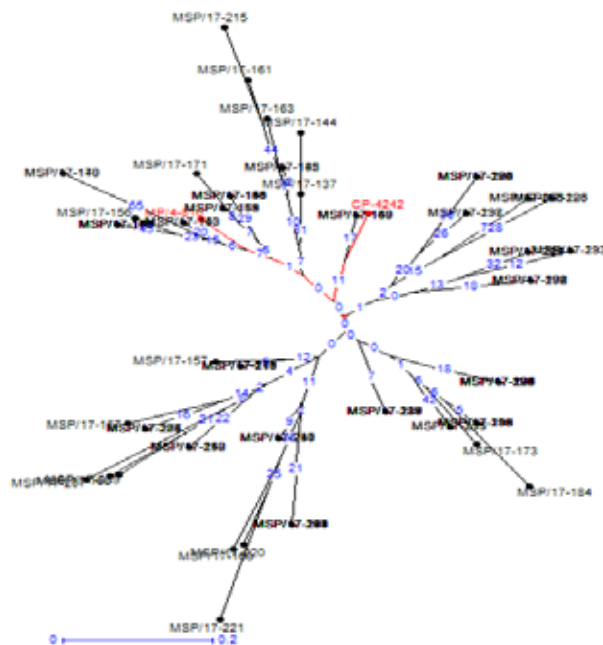


Fig. 4. Cluster analysis of 110 genotypes using STI0003 marker data based on unweighted Neighbour Joining method using the DARwin software with 100 bootstrap value.

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# EFFICACY OF NEW-CHEMISTRY INSECTICIDES AGAINST WHITEFLY AND APHIDS IN POTATO

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**ABSTRACT:** The efficacy of new-chemistry insecticides *viz.*, dinotefuran, diafenthiuron, flupyradifurone and pymetrozine was evaluated against whitefly, *Bemisia tabaci* and the peach-potato aphid, *Myzus persicae* in separate trials. Against whitefly adults, diafenthiuron 50 WP @ 0.08% and @ 0.1%, and pymetrozine 50 WG @ 0.06% and 0.08% performed best till 14 DAT with over 80% reduction in whitefly incidence. Against the peach-potato aphids, Flupyradifurone 200 SL @ 0.1%, diafenthiuron 50 WP @ 0.06% and 0.08% and pymetrozine 50 WG @ 0.04%, 0.06% and 0.08% performed on a par and reduced the aphid incidence by more than 80% throughout the period. Consequent incidence of viruses was also found lowest for the respective treatments. Therefore, diafenthiuron 50 WP @ 0.08% and pymetrozine 50 WG @ 0.06% can be used for the management of whiteflies, and flupyradifurone 200 SL @ 0.1%, diafenthiuron 50 WP @ 0.06% and pymetrozine 50 WG @ 0.04% can be used for the management of peach-potato aphids in potato crops.

**KEYWORDS:** Aphids, whitefly, virus transmission, systemic insecticides, seed potato, new chemistry insecticides, viruses, tuber yield

## INTRODUCTION

Potato crops are infested by a number of insect pests which can cause substantial reduction in tuber yield and quality. Among the sucking pests, aphids are the most important pests of potato worldwide. Aphids are sap feeding insects but the major damage inflicted is by transmission of numerous potato viruses limiting disease free seed production with a progressive decline in yield. More than fifteen species of aphids are known to infest potato crops in India (Bhatnagar *et al.*, 2017; Sridhar *et al.*, 2022). In India, in addition to the aphids, the sweetpotato whitefly, *Bemisia tabaci* (Gennadius) is a major concern as it transmits the begomovirus *Tomato leaf curl New Delhi virus-potato* (ToLCNDV[potato]) that causes the apical leaf curl disease in potato crops (Usharani *et al.*, 2004; Shah *et al.*, 2019; Kumar *et al.*, 2021). Disease incidence to the extent of 40–100% with heavy yield losses

and degeneration of seed stocks is reported (Lakra, 2003).

The sucking pests infesting potato crops have been managed with the use of systemic insecticides ever since the inception of seed plot technique. Commonly used insecticides include dimethoate, imidacloprid, thiamethoxam and phorate (Sharma *et al.*, 2012). While the use of such insecticides helps to reduce the vector population infesting potato crops, the use of insecticides with knockdown activity can be useful to kill the target insects before appreciable spread of the various potato viruses. Among the new chemistry pesticides, Pymetrozine, a pyridine-azomethine compound which paralyzes cibarium muscles and prevents certain Hemiptera from feeding (Smith and Giurcanu, 2014); Flupyradifurone and Dinotefuran, new generation neonicotinoid insecticides, which bind agonistically to nicotinic acetylcholine receptors in the central nervous system

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(Wakita *et al.*, 2003; Maluta *et al.*, 2021); and Diafenthiuron, a thiourea derivative which inhibits mitochondrial ATP synthase (Ishaaya *et al.*, 1993), are widely recommended for the management of whitefly and aphid vectors and to control the consequent spread of viruses. Therefore, in this study, we evaluated the acute and residual toxicity of these insecticides against major vector insects in potato crops.

## MATERIALS AND METHODS

Field experiments were conducted at ICAR-Central Potato Research Institute-Regional Station, Jalandhar (Punjab) during *rabi* 2018-19 and 2019-20 to evaluate the knockdown and residual toxicity of insecticides to adult whiteflies and aphids in potato crops. The experiments were laid in Randomised Complete Block Design, separately for evaluation against whitefly (*Bemisia tabaci*) and the peach-potato aphid (*Myzus persicae*). Crops were planted on 10<sup>th</sup> and 12<sup>th</sup> October for pesticide evaluation against whiteflies, and on 15<sup>th</sup> and 17<sup>th</sup> November for evaluation against aphids during the two years. Potato variety *Kufri Khyati* was grown in the experimental plots with a recommended package of agronomic practices without any crop protection measures.

A total of thirteen treatments were applied against both the whiteflies and aphids which included dinotefuran 20 SG @ 0.03% (0.3 gram per litre of water) and 0.04% (0.4 gram per litre), flupyradifurone 200 SL @ 0.05% (0.5 ml per litre), 0.75% (0.75 ml per litre) and 0.1% (1 ml per litre), diafenthiuron 50 WP @ 0.06% (0.6 gram per litre), 0.08% (0.8 gram per litre) and 0.1% (1 gram per litre), pymetrozine 50 WG @ 0.04% (0.4 gram per litre), 0.06% (0.6 gram per litre) and 0.08% (0.8 gram per litre) in comparison to imidacloprid 17.8 SL @ 0.04% (0.4 ml per litre) besides untreated control.

The treatments were replicated thrice. The insecticides were applied with a manually operated knapsack sprayer using 500 L of water/ha.

Observations on the number of insects *i.e.*, adult whiteflies or adults and 3<sup>rd</sup> and 4<sup>th</sup> instar nymphs of peach-potato aphid were taken from five randomly selected plants per plot (plot size 3.6 × 3.2 m) one day before treatment (pre-count) and 1, 3, 7 and 14 days after treatment (DAT). The numbers were counted from three leaves on each plant, one each from upper, middle and lower strata. Pesticide treatments were given at 80% crop emergence for whitefly trials and at 50 days after emergence in case of aphid trials.

The per cent reduction in pest population size over control was calculated using the Henderson-Tilton's formula (Henderson and Tilton, 1955). The total tuber yield in all experiments was recorded on a whole plot basis. Percent virus incidence (expressed as percentage of infected plants over total number of plants/plot) was noted three weeks after the last observation on whitefly/aphid population size. Observations based on the symptoms of potato apical leaf curl virus (PALCV) disease were noted in whitefly trials, and on the incidence of mild and severe mosaic and leaf roll in aphid management trials. The data on number of insects, per cent population reduction over control and tuber yield were subjected to analysis of variance (ANOVA) after appropriate transformation. The treatment means were separated by least significant difference (LSD) test at 5% level of significance.

## RESULTS AND DISCUSSION

### Whitefly, *Bemisia tabaci*

The error mean squares of the per cent pest incidence reduction were homogeneous over the two years, therefore data were

pooled for analysis. The effect of insecticide treatments on the average incidence of adult whiteflies on potato are shown in Table 1. None of the tested insecticides had a significant knockdown effect (1 DAT) on the incidence of adult whiteflies however, diafenthiuron 50 WP @ 0.1% and pymetrozine 50 WG @ 0.06% and @ 0.08% performed best with  $55.4 \pm 4.69\%$ ,  $54.7 \pm 1.60\%$  and  $52.3 \pm 7.01\%$  reduction in whitefly incidence, respectively in comparison to imidacloprid 17.8 SL @ 0.04% ( $52.3 \pm 5.43\%$ ) ( $F = 35.18$ ,  $d.f. = 12, 24$ ,  $p = 0.00$ ). All the tested insecticides exhibited maximum toxicity at 7 DAT and by 14 DAT, slight to appreciable decline in toxicity of all the insecticides was observed.

For dinotefuran 20 SG, slight increase in the toxicity was noted as the dose increased from 0.03 to 0.04% however, maximum reduction in whitefly incidence

achieved with dinotefuran 20 SG @ 0.04% was  $57.9 \pm 4.38\%$  at 7 DAT. Similarly, the toxicity of flupyradifurone 200 SL increased with increasing dose with maximum reduction in whitefly incidence achieved with flupyradifurone 200 SL @ 0.1% was  $66.4 \pm 1.46\%$  at 7 DAT. Opposite to these, the efficacy of diafenthiuron 50 WP increased appreciably with increase in dosage. By 7 DAT, diafenthiuron 50 WP @ 0.1% reduced the adult whitefly incidence by  $83.1 \pm 1.34\%$  and by 14 DAT, diafenthiuron 50 WP @ 0.08% and @ 0.1% performed at par with  $76.2 \pm 1.38\%$  to  $80.4 \pm 1.15\%$  reduction in whitefly incidence. Similarly, pymetrozine 50 WG exhibited high level of toxicity against adult whiteflies. Pymetrozine 50 WG @ 0.06% and 0.08% performed at par and reduced the adult whitefly incidence by  $84.9 \pm 0.99\%$  to  $85.6 \pm 1.35\%$  at 7 DAT. At 14 DAT, the

Table 1: Efficacy of knockdown insecticides against whitefly, *Bemisia tabaci* in potato

| No. | Treatments                      | Pre-Count        | Per cent reduction over control |                        |                        |                        | % Virus incidence     |
|-----|---------------------------------|------------------|---------------------------------|------------------------|------------------------|------------------------|-----------------------|
|     |                                 |                  | 1 DAT                           | 3 DAT                  | 7 DAT                  | 14 DAT                 |                       |
| 1.  | Dinotefuran 20 SG @ 0.03%       | $13.33 \pm 0.88$ | $30.1 \pm 9.30$ (5.46)          | $43.1 \pm 2.88$ (6.63) | $50.0 \pm 6.46$ (7.11) | $50.9 \pm 2.86$ (7.20) | $8.3 \pm 1.6$ (3.03)  |
| 2.  | Dinotefuran 20 SG @ 0.04%       | $13.0 \pm 0.58$  | $37.1 \pm 2.28$ (6.16)          | $49.8 \pm 1.70$ (7.12) | $57.9 \pm 4.38$ (7.66) | $56.4 \pm 3.94$ (7.56) | $8.3 \pm 2.8$ (2.96)  |
| 3.  | Flupyradifurone 200 SL @ 0.05%  | $11.0 \pm 1.00$  | $40.0 \pm 2.40$ (6.39)          | $35.0 \pm 8.40$ (5.91) | $48.1 \pm 2.95$ (7.00) | $52.4 \pm 2.74$ (7.30) | $7.4 \pm 0.9$ (2.88)  |
| 4.  | Flupyradifurone 200 SL @ 0.075% | $11.33 \pm 0.33$ | $31.9 \pm 4.65$ (5.70)          | $37.3 \pm 6.94$ (6.12) | $64.1 \pm 5.48$ (8.05) | $61.5 \pm 4.21$ (7.89) | $7.4 \pm 2.4$ (2.82)  |
| 5.  | Flupyradifurone 200 SL @ 0.1%   | $11.0 \pm 0.58$  | $39.7 \pm 2.34$ (6.37)          | $46.3 \pm 4.42$ (6.85) | $66.4 \pm 1.46$ (8.21) | $64.3 \pm 2.08$ (8.07) | $7.4 \pm 0.9$ (2.88)  |
| 6.  | Diafenthiuron 50 WP @ 0.06%     | $12.33 \pm 0.33$ | $37.4 \pm 4.28$ (6.17)          | $50.9 \pm 5.91$ (7.18) | $65.0 \pm 3.23$ (8.12) | $57.6 \pm 2.45$ (7.65) | $9.3 \pm 0.9$ (2.19)  |
| 7.  | Diafenthiuron 50 WP @ 0.08%     | $11.0 \pm 0.58$  | $48.6 \pm 3.96$ (7.02)          | $57.6 \pm 1.51$ (7.65) | $65.6 \pm 5.73$ (8.14) | $76.2 \pm 1.38$ (8.78) | $7.4 \pm 0.9$ (2.88)  |
| 8.  | Diafenthiuron 50 WP @ 0.10%     | $13.33 \pm 0.88$ | $55.4 \pm 4.69$ (7.49)          | $66.6 \pm 2.78$ (8.21) | $83.1 \pm 1.34$ (9.17) | $80.4 \pm 1.15$ (9.02) | $6.5 \pm 2.4$ (2.66)  |
| 9.  | Pymetrozine 50 WG @ 0.04%       | $13.33 \pm 1.20$ | $39.9 \pm 5.98$ (6.36)          | $52.7 \pm 3.22$ (7.32) | $69.8 \pm 3.66$ (8.40) | $60.7 \pm 2.25$ (7.85) | $8.3 \pm 0.0$ (3.05)  |
| 10. | Pymetrozine 50 WG @ 0.06%       | $13.0 \pm 1.53$  | $54.7 \pm 1.60$ (7.46)          | $67.9 \pm 0.64$ (8.30) | $84.9 \pm 0.99$ (9.26) | $79.9 \pm 1.15$ (8.99) | $7.4 \pm 0.9$ (2.88)  |
| 11. | Pymetrozine 50 WG @ 0.08%       | $12.0 \pm 0.58$  | $52.3 \pm 7.01$ (7.27)          | $69.6 \pm 1.73$ (8.39) | $85.6 \pm 1.35$ (9.30) | $81.8 \pm 3.91$ (9.09) | $6.5 \pm 0.9$ (2.72)  |
| 12. | Imidacloprid 17.8 SL @ 0.04%    | $13.0 \pm 0.58$  | $52.3 \pm 5.43$ (7.28)          | $59.8 \pm 1.99$ (7.79) | $84.5 \pm 2.57$ (9.24) | $82.9 \pm 4.05$ (9.15) | $7.4 \pm 0.9$ (2.88)  |
| 13. | Control                         | $\pm 1.53$       | 0                               | 0                      | 0                      | 0                      | $10.2 \pm 1.9$ (3.32) |
| SEm |                                 |                  | 0.28                            | 0.29                   | 0.17                   | 0.12                   | 0.26                  |
| CD  |                                 |                  | 0.83                            | 0.86                   | 0.50                   | 0.36                   | NA                    |

Values are mean  $\pm$  SE, NA = Not applicable,

Values in parenthesis are square root transformed as  $\sqrt{x} + 1$ .

corresponding figures were noted as  $79.9 \pm 1.15\%$  and  $81.8 \pm 3.91\%$ , respectively.

Incidence of PALCV disease was considerably lower in diafenthiuron 50 WP @ 0.1% ( $6.50 \pm 2.43\%$ ) and pymetrozine 50 WG @ 0.08% ( $6.50 \pm 0.90\%$ ) as compared to untreated control ( $10.16 \pm 1.86\%$ ) with no significant variation among the treatments ( $F = 0.84$ ,  $d.f. = 12, 24$ ,  $p = 0.61$ ). No phytotoxicity symptoms were associated with any of the treatments and the total tuber yield showed insignificant variation among the treatments ( $F = 1.09$ ,  $d.f. = 12, 24$ ;  $p = 0.40$ ) (data not shown).

### Peach potato aphid, *Myzus persicae*

The tested insecticides exhibited significant knockdown effect against the peach-potato aphid ( $F = 201.15$ ,  $d.f. = 12, 24$ ,  $p = 0.00$ ) (Table 2). Flupyradifurone 200 SL @ 0.1% and diafenthiuron 50 WP @ 0.1% performed best with  $74.60 \pm 1.60\%$  and  $75.60 \pm 2.82\%$  reduction in the incidence of aphids at 1 DAT. All the tested insecticides performed consistently up to 14 DAT, except dinotefuran 20 SG. For dinotefuran 20 SG @ 0.04%, maximum reduction in the incidence of aphids was noted at 3 DAT ( $71.91 \pm 2.63\%$ ) which decreased subsequently.

**Table 2: Efficacy of knockdown insecticides against peach-potato aphid, *Myzus persicae* in potato**

| No. | Treatments                      | Pre-Count        | Per cent reduction over control |                            |                            |                            | % Virus Incidence        |
|-----|---------------------------------|------------------|---------------------------------|----------------------------|----------------------------|----------------------------|--------------------------|
|     |                                 |                  | 1 DAT                           | 3 DAT                      | 7 DAT                      | 14 DAT                     |                          |
| 1.  | Dinotefuran 20 SG @ 0.03%       | $13.00 \pm 0.58$ | $59.95 \pm 0.00$<br>(7.81)      | $67.68 \pm 5.41$<br>(8.27) | $65.53 \pm 5.96$<br>(8.14) | $60.07 \pm 2.25$<br>(7.81) | $9.6 \pm 1.8$<br>(3.24)  |
| 2.  | Dinotefuran 20 SG @ 0.04%       | $13.33 \pm 0.33$ | $67.46 \pm 1.63$<br>(8.27)      | $71.91 \pm 2.63$<br>(8.53) | $66.77 \pm 4.83$<br>(8.22) | $64.66 \pm 1.58$<br>(8.10) | $9.6 \pm 1.8$<br>(3.24)  |
| 3.  | Flupyradifurone 200 SL @ 0.05%  | $12.00 \pm 0.58$ | $69.27 \pm 3.63$<br>(8.37)      | $76.38 \pm 0.83$<br>(8.79) | $85.61 \pm 3.13$<br>(9.30) | $74.42 \pm 2.22$<br>(8.68) | $8.8 \pm 2.3$<br>(3.08)  |
| 4.  | Flupyradifurone 200 SL @ 0.075% | $14.00 \pm 0.00$ | $70.56 \pm 1.53$<br>(8.45)      | $76.50 \pm 2.96$<br>(8.80) | $87.66 \pm 2.66$<br>(9.41) | $78.08 \pm 1.91$<br>(8.89) | $8.8 \pm 0.9$<br>(3.11)  |
| 5.  | Flupyradifurone 200 SL @ 0.1%   | $13.67 \pm 0.33$ | $74.60 \pm 1.60$<br>(8.69)      | $82.59 \pm 3.75$<br>(9.13) | $89.93 \pm 2.67$<br>(9.53) | $87.98 \pm 1.50$<br>(9.43) | $7.0 \pm 0.9$<br>(2.82)  |
| 6.  | Diafenthiuron 50 WP @ 0.06%     | $12.00 \pm 0.58$ | $69.27 \pm 3.63$<br>(8.37)      | $76.38 \pm 0.83$<br>(8.79) | $77.06 \pm 3.33$<br>(8.83) | $82.42 \pm 3.12$<br>(9.12) | $10.5 \pm 1.5$<br>(3.38) |
| 7.  | Diafenthiuron 50 WP @ 0.08%     | $12.33 \pm 0.88$ | $73.62 \pm 3.06$<br>(8.63)      | $77.43 \pm 6.03$<br>(8.84) | $83.36 \pm 0.40$<br>(9.18) | $88.53 \pm 0.20$<br>(9.46) | $8.8 \pm 0.9$<br>(3.11)  |
| 8.  | Diafenthiuron 50 WP @ 0.10%     | $13.33 \pm 0.88$ | $75.60 \pm 2.82$<br>(8.74)      | $79.12 \pm 5.57$<br>(8.94) | $84.61 \pm 0.40$<br>(9.25) | $89.48 \pm 2.89$<br>(9.50) | $6.1 \pm 2.3$<br>(2.60)  |
| 9.  | Pymetrozine 50 WG @ 0.04%       | $13.00 \pm 0.00$ | $61.62 \pm 1.66$<br>(7.91)      | $71.19 \pm 2.70$<br>(8.49) | $84.21 \pm 0.40$<br>(9.23) | $89.12 \pm 0.20$<br>(9.49) | $9.6 \pm 1.9$<br>(3.24)  |
| 10. | Pymetrozine 50 WG @ 0.06%       | $12.33 \pm 0.33$ | $66.58 \pm 3.50$<br>(8.21)      | $80.71 \pm 4.15$<br>(9.03) | $89.04 \pm 2.43$<br>(9.48) | $92.32 \pm 2.01$<br>(9.66) | $7.0 \pm 0.9$<br>(2.82)  |
| 11. | Pymetrozine 50 WG @ 0.06%       | $12.33 \pm 0.88$ | $70.10 \pm 1.76$<br>(8.42)      | $84.40 \pm 4.50$<br>(9.23) | $91.68 \pm 0.19$<br>(9.62) | $94.27 \pm 0.10$<br>(9.76) | $6.1 \pm 0.9$<br>(2.66)  |
| 12. | Imidacloprid 17.8 SL @ 0.04%    | $13.67 \pm 0.33$ | $71.43 \pm 2.74$<br>(8.50)      | $86.30 \pm 3.16$<br>(9.34) | $89.93 \pm 2.67$<br>(9.53) | $82.81 \pm 1.40$<br>(9.15) | $8.8 \pm 0.9$<br>(3.11)  |
| 13. | Control                         | $13.67 \pm 0.33$ | 0                               | 0                          | 0                          | 0                          | $11.4 \pm 1.8$ (3.50)    |
| SEm |                                 |                  | 0.15                            | 0.21                       | 0.15                       | 0.09                       | 0.22                     |
| CD  |                                 |                  | 0.42                            | 0.63                       | 0.44                       | 0.29                       | NA                       |

Values are mean  $\pm$  SE, NA = Not applicable,

Values in parenthesis are square root transformed as  $\times x + 1$ .

Opposite to this, flupyradifurone 200 SL @ 0.05%, 0.075% and 0.1% performed at par and reduced the aphid incidence by 76.38 to 82.59% at 3 DAT, by 85.61 to 89.93% at 7 DAT. At 14 DAT, the highest dose reduced the aphid incidence by  $87.98 \pm 1.50\%$  which was significantly higher than the lower doses (74.42 to 78.08%). Similarly, diafenthiuron 50 WP @ 0.06% and 0.08% performed equally and reduced the aphid incidence by 76.38 to 79.12% at 3 DAT, by 77.06 to 83.36% at 7 DAT, and by 82.42 to 88.53% at 14 DAT. Pymetrozine 50 WG performed best with highest residual toxicity against the peach-potato aphid. Pymetrozine 50 WG @ 0.04%, 0.06% and 0.08% performed almost on a par and reduced the aphid incidence by 71.19 to 84.40% at 3 DAT, by 84.21 to 91.68% at 7 DAT, and by 89.12 to 94.27% at 14 DAT.

The incidence of mild and severe mosaic, and leaf roll symptoms was lowest in pymetrozine 50 WG @ 0.08% ( $6.16 \pm 0.86\%$ ), diafenthiuron 50 WP @ 0.1% ( $6.1 \pm 2.3\%$ ), and flupyradifurone 200 SL @ 0.1% ( $7.03 \pm 0.86\%$ ) as compared to control ( $11.43 \pm 1.76\%$ ) with no statistically significant variation among the treatments ( $F = 1.44$ ,  $d.f. = 12, 24$ ,  $p = 0.21$ ). Again, no phyto-toxicity symptoms were associated with any of the treatments and the total tuber yield showed insignificant variation among the treatments ( $F = 1.09$ ,  $d.f. = 12, 24$ ;  $p = 0.40$ ) (data not shown).

Razaq *et al.* (2005) reported the highest mortality of whiteflies for diafenthiuron which was statistically different from imidacloprid and acetamiprid. Diafenthiuron and acetamiprid also proved effective after 7 days of application. Kalyan *et al.* (2017) reported that seven days after spray, the maximum percent reduction in jassids and whitefly population was recorded in difenthiuron 50 WP. Venkateshalu and Math

(2017) reported that dinotefuran 20% SG @ 30 g a.i. was significantly superior and recorded a lower whitefly population.

Whitworth *et al.* (2016) reported significant control of aphids, *Melanaphis sacchari* on sorghum with flupyradifurone 200 SL at Kansas University. Three evaluated doses of flupyradifurone 200 SL performed the best in suppressing rosy apple aphids, *Dysaphis plantaginea* on apple up to 26 days post-treatment (Alston and Lindstrom, 2012). Flupyradifurone 200 SL was found most effective in suppressing jassids and whiteflies population on brinjal. Similar results were reported by Kumar *et al.* (2017) against whitefly eggs and nymphs. Nauen *et al.* (2014) reported excellent field control of lettuce aphids with Flupyradifurone (SL 200) at 125 g/ha after foliar application.

Roditakis *et al.* (2017) reported significant inhibition of *Tomato yellow leaf curl virus* (TYLCV) transmission by flupyradifurone compared to thiamethoxam. Similar results were reported by Maluta *et al.* (2021) who found significant suppression in the incidence of *Tomato chlorosis virus* (ToCV) after treatment of tomato seedlings with flupyradifurone.

## CONCLUSION

It is concluded that the tested insecticides are not useful as knockdown insecticides against whitefly adults while Flupyradifurone 200 SL @ 0.1% and diafenthiuron 50 WP @ 0.1% exhibited significant knockdown activity against peach-potato aphids. Against whitefly adults, diafenthiuron 50 WP @ 0.08% and @ 0.1%, and pymetrozine 50 WG @ 0.06% and 0.08% performed best till 14 DAT with over 80% reduction in incidence. Consistent with this, the lowest incidence of PALCV disease was noted for the respective diafenthiuron and pymetrozine treatments.

Therefore, diafenthiuron 50 WP @ 0.08% and pymetrozine 50 WG @ 0.06% can be used for the management of whiteflies in potato crops. Against the peach-potato aphids, Flupyradifurone 200 SL @ 0.1%, diafenthiuron 50 WP @ 0.06% and 0.08% and pymetrozine 50 WG @ 0.04%, 0.06% and 0.08% performed equally and reduced the aphid incidence by more than 80% throughout the period. The lowest incidence of mild and severe mosaic and leaf roll symptoms was noted for the respective treatments. Therefore, flupyradifurone 200 SL @ 0.1%, diafenthiuron 50 WP @ 0.06% and pymetrozine 50 WG @ 0.04% can be used for the management of peach-potato aphids in potato crops.

## CONFLICTS OF INTEREST

The authors confirm that this manuscript has no conflicts of interest

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# AN ANALYTICAL STUDY OF POTATO SEED PRODUCTION IN JALANDHAR DISTRICT OF PUNJAB

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**ABSTRACT:** Seed is an essential input for the potato crop. Much of the efforts and investment would be infructuous if the farmers did not get the quality seeds. Only the seed with assured purity-genetic and physical can be expected to respond to fertilizers and other inputs in a respected manner. The present study attempted to analyze the source, SRR of potato seed and assess the effect on potato crop yield by using certified seed in the Jalandhar district of Punjab. The current study was conducted on primary data collected from 120 farmers during the 2020-21 agricultural year. The data were analyzed using simple tabular analysis and other suitable statistical techniques. The study found that the most preferred source of seed was the self-retained seed which came out to be 48 per cent, the second most preferred source was private seed dealers, as 17 per cent procured seed from these dealers. The high use of self-retained seed was due to the high cost of purchased seed, and the other reason was that farmers had more confidence in the self-retained seed. The study found that large farmers' Seed Replacement Rate (SRR) was higher. It was 11.2 per cent for small farmers, 19.5 per cent for medium farmers and 27.5 per cent for large farmers. The yield of potato crop using certified seed was higher than non-certified seed. The per cent difference in yield of potato grown by certified and non-certified seed among small and medium farmers was 17 per cent, 11 per cent among large farmers and 15 per cent overall in the Jalandhar district of Punjab. The study highlighted that the primary constraint faced by potato seed growers were high prices of certified seed (69.1 per cent), high cost of pesticides and insecticides (65.8 per cent), fluctuations in the price of potato seed (55 per cent), lack of public procurement at MSP (53.3 per cent), covid related restrictions (52.5 per cent) and lack of extension facilities (48.3 per cent). The study suggested that the government should provide certified seed to the farmers at the lowest cost to increase the seed replacement rate. Awareness regarding the use of certified seed should be given to farmers through extension services. Government institutes like Central Potato Research Station (CPRS) (ICAR), the Centre of Excellence (Dogri) and the Department of Horticulture should expand the production of certified seeds as only 18 per cent of potato growers purchased seeds from these agencies in the study area. The minimum support price of potatoes should be fixed to promote the production of potatoes in the state.

**KEYWORDS:** Potato, seed replacement rate, source, certified, non-certified

## INTRODUCTION

Vegetable production is one of the potential alternatives due to the short cultivation period, small investment (unlike fruits), and growing demand. Potato is the principal vegetable crop of Punjab. During 2019-20, the area under vegetables was about 2.73 lakh hectares in Punjab. Out of this 73.79, per cent area was under potato crop. It may be stated that the area under vegetables was 1.46 of the total cropped area of Punjab during the year 2019-20. The figure was 1.06 per cent in the case of Potato. The potato production was about 2870 thousand

metric tonnes in 2019-20 (Government of Punjab 2020). Punjab's share in India's potato production is about five per cent. (Government of India, 2019; Anantia, 2008; Jairath, 2008; Dastagiri *et al.*, 2009). Seed is an essential input for the potato crop. Much of the efforts and investment will be fructuous if the farmer does not get quality seeds. Only the seed with assured purity-genetic and physical, can be expected to respond to fertilizers and other agricultural inputs. The farmer's returns from the other costly inputs like machinery, irrigation, chemical fertilizers, pesticides, etc., from his land and

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labour, depends upon the seed. Even in an agriculturally developed state like Punjab, it was 3.48 per cent for certified seeds and 4.43 per cent for quality seeds, seed should be replaced every year for hybrid varieties and every four years or sooner for open-pollinated crops like wheat and paddy (Sidhu, 1995). The low replacement of certified seeds could be due to the high price and non-availability at the proper times (Sidhu *et al.*, 1997). Production of good quality seed will be of no value if it does not reach the farmers in time and at an affordable price. The production of certified seeds is far below the actual requirements for different crops in the country. In Punjab, the farmers used 90.51 per cent of self-retained seed from the previous autumn crop of potato. Due to the high cost of purchased seed, the farmers used the self-retained seed, which is usually inferior. Moreover, the general farm produce retained for seed cannot be substituted for quality seed, and it generally lacks genetic vigour and has a poor germination rate (Singh *et al.*, 1990). To increase productivity and production of potatoes, certified/quality seeds can also play an essential role in the state. One major constraint resulting in lower productivity in the country (21.1t/ha) is the use of poor-quality seeds (NHB, 2015). Successive multiplication of seed tubers in the field magnifies the risk of infection and build-up of several bacterial, fungal, nematode and viral pathogens. Degenerated seed lowers the productivity to the extent of about 40 per cent (Salazar, 1996). Keeping in view the importance of potato seed, the

present study was undertaken to identify the different sources of potato seed, determine the difference in yield of potato crop raised with certified and non-certified, and determine the seed replacement rate (SSR) in Jalandhar district of Punjab.

## MATERIALS AND METHODS

The study was conducted in Jalandhar district as the area under potato was maximum in this district, i.e., 23 per cent. The four-stage stratified random cum purposive sampling technique was used with the district as the first stage unit, development block as the second, village as the third and the farmers as the fourth and the ultimate unit of the study. One major potato-growing district was purposively selected for the study in the first stage. In the second stage, two potato growing development blocks were selected. In the third stage, three villages were selected randomly from each selected block. In the fourth stage, 60 potato seed growers were chosen randomly from the cluster of villages chosen from each block. In this way, the total sample comprised 120 farmers. The detail in this regard is given in (Table 1).

The farmers were categorised into small, medium and large categories based on the area under potato by using the cube root frequency method. To make the sample design self-weighting, the number of farmers selected from each size category was proportion to their number in that category. Primary data was collected from selected farmers to achieve the study's objectives. Information was collected from

**Table 1: Selected district, blocks, villages and number of farmers in the study area**

| Selected Districts | Selected blocks | Selected villages                     | No. of Farmers |
|--------------------|-----------------|---------------------------------------|----------------|
| Jalandhar          | Jalandhar east  | Qadianwali, Sansarpur and DhanalKalan | 60             |
|                    | Bhogpur         | Bhullowal, Kurala and Jamalpur        | 60             |
| Grand Total        |                 |                                       | 120            |

Source: Field survey

respondents chosen regarding variety-wise areas, the production yield of potato for certified and non-certified potato seed users, sources of potato seed, seed rate, etc. The secondary data were obtained from the reputed published and unpublished sources, keeping the study's objectives. The Primary and secondary data were analysed using the appropriate statistical tools such as frequency distribution, averages, percentages, etc.

The Seed replacement rate (SRR) of potato crop with the sample farmers for certified seeds during 2019-20 was calculated by taking a percentage of the certified seed to the total seed used for the potato crop.

$$SRR = \frac{C \times 100}{A \times K}$$

Where,

SRR = seed replacement rate for a particular crop

C = certified seeds used by the farmers

A = area under the crop

K = seed rate per unit of area.

To test the significance of the difference between the yield of the crop raised with certified and non-certified seeds, t-test was applied as under:

$$t = \frac{m_1 - m_2}{s \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} = \frac{m_1 - m_2}{s} \sqrt{\frac{n_1 n_2}{n_1 + n_2}}$$

$$S = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}}$$

## RESULTS AND DISCUSSIONS

### Variety-wise area distribution

The varieties of potato can be divided into three categories depending on the duration of the crop, i.e., a) early varieties, b) medium varieties, and c) late varieties (Vashisht and Lal, 2005c). Kufri Pukhraj yields 130 qtl. Per acre in 70-90 days. The maturity period for Kufri Jyoti is about 90-110 days and yields about 80-120 per acre Kufri Badshah is a late variety, and its expected yield is 130 qtl. Per acre within the maturity period of

100-110 days, whereas these figures for Kufri Ashoka are 110 qtl. Per acre and 75-80 days, respectively. Overall, 43 per cent of selected farmers preferred Kufri Pukhraj, 36 per cent of farmers preferred Kufri Jyoti, and 14.2 per cent of the selected cultivate Kufri Badshah in the Jalandhar district of Punjab (Table 2). Most of the farmers cultivate the Kufri Pukhraj variety due to its resistance to early blight and moderately resistant to late blight disease. Moreover, it is easy to cook variety with a waxy texture and mild flavour and also it is free from discolouration after cooking.

### Sources of Potato seed

Seed is an essential input for different crops. Healthy seeds in vegetatively propagated crops like potato are critical (Vashisht and Lal, 2005). In developing countries, farmers often have three significant sources of seed: seed purchased from the seed industry or cold stores, seed obtained from the other farmers and seed retained from the previous year's crop. The farmer himself produced more than 85 per cent of the seed consumed in India. Moreover, the Punjab state has established itself as a seed-producing state of potato (Vashisht *et al.*, 2005). The share of the organised seed sector is meagre because of the high price of certified seeds and their non-availability in terms of proper place and time (Verma and Sidhu, 2009). It is essential to mention

**Table 2: Variety-wise area of potato cultivated by the selected farmers in Jalandhar district**

| Variety       | Small     | Medium    | Large     | Overall   |
|---------------|-----------|-----------|-----------|-----------|
| Kufri Pukhraj | 20 (50)   | 17 (42.5) | 15 (37.5) | 52 (43.3) |
| Kufri Jyoti   | 15 (37.5) | 15 (37.5) | 13 (32.5) | 43 (35.8) |
| Kufri Badshah | 3 (7.5)   | 6 (15)    | 8 (20)    | 17 (14.2) |
| Any other     | 2 (5)     | 2 (5)     | 4 (10)    | 8 (6.7)   |
| Total         | 40 (100)  | 40 (100)  | 40 (100)  | 120 (100) |

Source: Field survey

here that the seed consumption is higher in the case of the potato because of its higher seed rate. As a result, seeds alone accounted for 38-40 per cent of the total cost of potato production (Dahiya and Singh, 1992; Sah *et al.*, 2010).

The source of potato seed by selected farmers is shown in Table 3. The results revealed that most of the sampled small, about 38 per cent used self-retained seed, followed by seed from private seed dealers, about 25 per cent, 8 per cent from relatives/friends and cold storage and 5 per cent from CPRS, Centre of Excellence and fellow farmers. Among the medium farmers, 45 per cent of farmers used self-retained seed, followed by seed from private seed dealers, about 15 per cent, 13 per cent of farmers used cold storage seed, 8 per cent of farmers used seed from fellow farmers and the Department of Horticulture (Pb), about 5 per cent of farmers from CPRS and Centre of Excellence and only 3 per cent of farmers used seed from relatives/friends. Among large farmers, 63 per cent of farmers used self-retained seed, followed by 13 per cent from CPRS, 10 per cent from Centre of Excellence, Dhogri (Jalandhar), 8 per cent from cold storage, 5 per cent from the Department of Horticulture, PAU

(Ludhiana) and only 3 per cent of farmers followed private seed dealer. Overall, about 48 per cent used self-retained seed, followed by seed from private seed dealers (about 17 per cent) and cold storage it's (about 9 per cent), 8 per cent from CPRS, 7 per cent followed by Centre of Excellence Dhogri (Jalandhar), about 4 per cent of farmers went by Fellow farmers and Dept. of Horticulture PAU (Ludhiana), Only 3 per cent of farmers used seed from relatives/friends. The high use of self-retained seed may be due to the high cost of the purchased seed. Moreover, the farmers had more confidence in the self-retained seed. The potato seed from friends or relatives was either free or exchanged in barter. The potato farmers were very much conscious of the quality of the potato seed.

Seed Rate is the quantity of seed of a crop required to sow a unit area of land for optimum crop production. Using the recommended seed rate is necessary for maintaining the optimum plant population in the field for a higher yield harvest. It is also required to prevent seed wastage from excess sowing, which reduces the initial cost of production. It is also necessary to know the quantity of seed needed for sowing in advance and ensure quality crop production. The recommended seed rate by PAU for

**Table 3: Sources for the seed of potato crop of selected farmers in Jalandhar district**

| Source of potato seed         | Small     | Medium   | Large     | Overall   |
|-------------------------------|-----------|----------|-----------|-----------|
| Self-retained seed            | 15 (37.5) | 18 (45)  | 25 (62.5) | 58 (48.3) |
| Fellow farmers                | 2 (5)     | 3 (7.5)  | 0 (0)     | 5 (4.1)   |
| Relatives/friends             | 3 (7.5)   | 1 (2.5)  | 0 (0)     | 4 (3.3)   |
| Centre of excellence (Dogri)  | 2 (5)     | 2 (5)    | 4 (10)    | 8 (6.6)   |
| Cold storage                  | 3 (7.5)   | 5 (12.5) | 3 (7.5)   | 11 (9.1)  |
| CPRS (ICAR)                   | 2 (5)     | 2 (5)    | 5 (12.5)  | 9 (7.5)   |
| Dept. of Horticulture, Punjab | 0 (0)     | 3 (7.5)  | 2 (5)     | 5 (4.1)   |
| Private seed dealer           | 13 (25)   | 6 (15)   | 1 (2.5)   | 20 (16.6) |
| Total                         | 40 (100)  | 40 (100) | 40 (100)  | 120(100)  |

Source: Field Survey

Potato crops is 13-18 Qtl/acre for all varieties. The seed rate adopted was highest among large farmers (15.4 Qtl/acre), followed by selected medium farmers (15.2 Qtl/acre) and 14.3 Qtl/acre by small farmers in the study area (Table 4).

### The seed replacement rate of sample farmers

The number of generations up to which the seed could be used from the previous crop season without resorting to renewal is another crucial aspect and vital for the maintenance of the productivity of crops. The deterioration in the quality of seed may result from physical admixtures and loss of genetic vigour and germination power. The admixture may occur in the field, at the threshing yard or even in storage when seeds of other varieties and other crops get mixed with the variety. The deterioration in the quality of seed results in a loss of productivity per unit of area. The seed renewal period recommended by the International Potato Centre; in Lima (Peru) is four years for the potato crop. It is generally assumed that high SRR holds the key to higher production. But in Punjab, as per official figures, the SRRs were low, but productivity continued to be the highest in the country because the actual SRRs of quality seeds were high. The progressive farmers of Punjab exchanged quality seeds among themselves. In this way, farmer to farmer exchange of seeds is very common in Punjab.

**Table 4: Potato seed rate in Jalandhar district**

| Farm Category | Seed rate (q/acre) | Recommended Seed Rate by PAU (Qtl/acre) |
|---------------|--------------------|-----------------------------------------|
| Small         | 14.3               | 13-18                                   |
| Medium        | 15.2               | 13-18                                   |
| Large         | 15.4               | 13-18                                   |
| Average       | 14.9               | 13-18                                   |

Source: - Field Survey

The barter system of seeds among the farmers was an ancient form of transaction of seeds and formed the most popular source of seeds (Reddy, 1989). The economically poor and traditionally conservative farmers preferred to procure seeds locally from the farmers who had already grown good crops. Besides practising the barter system of sources, the farmers also made cash payments to their fellow farmers. The seeds were also given free by fellow farmers and relatives in some cases. The farmers preferred this source because of its reliability (Sidhu, 1995). In Punjab, the lateral spread of seed among the farmers was high. Moreover, the yield of a crop was also affected by many other inputs. The SRRs in the case of sample farmers for certified seeds for potato crops have been worked out separately and discussed in Table 5. The sample farmers took the certified seeds from the Centre of Excellence Dhogri (Jalandhar), Central Potato Research Station (Jalandhar) and Departments of Horticulture. The study showed that the SRR of selected farmers was 19.5 per cent for the potato crop. Due to this factor, the SRR was low for the potato crop.

The seed Replacement Rate was found to be 19.5 per cent in the Jalandhar district of Punjab. It was highest for large farmers, i.e., 27.5 per cent, 19.8 per cent for medium farmers and 11.2 per cent for small farmers in the study area. Seed replacement rate was higher among large farmers due to the better economic condition of large farmers

**Table 5: Seed Replacement Rate of Certified Seed of Potato crop in Jalandhar district**

| Farm Category | Seed Replacement Rate (%) |
|---------------|---------------------------|
| Small         | 11.2                      |
| Medium        | 19.8                      |
| Large         | 27.5                      |
| Average       | 19.5                      |

Source: Field Survey

to buy seed from institutional sources and their more heightened awareness about the quality of seed.

The Yield difference was found by taking into account the sample farmers who used both certified and non-certified seeds. There was 10 per cent of small farmers, 18 per cent of medium and 28 per cent of large farmers who used both certified and non-certified seed in the study area (Table 6). The yield of potato crops using certified seed was higher than non-certified seed. The percentage difference among small and medium farmers was 17 per cent, 11 per cent among large farmers and 15 per cent overall in the Jalandhar district. The yield of the crop planted was statistically high at a five per cent level of significance among all farm size categories in the study area.

Farmers faced many constraints in potato seed production. An opinion survey was carried out in the study area to determine the constraints/problems faced by various farmers. Among small farmers, the main problem was high prices of insecticides and pesticides (70 per cent), followed by high costs of certified seed (63 per cent), covid-related restrictions (48 per cent), fluctuation in prices of potato seed (45 per cent), pest and disease attack (38 per cent), lack of access to extension services (35 per cent), no public procurement at the MSP (30 per

cent), non-availability of labour during peak period (25 per cent), certified seed availability not at the appropriate time (23 per cent) (Table 7). Among medium farmers, the primary constraint was high prices of certified seed (68 per cent), followed by the high cost of insecticides and pesticides (65 per cent), the problem faced by farmers due to fluctuation of prices and no public procurement at the MSP was (58 per cent) each, covid related restriction (53 per cent), lack of access to extension services (50 per cent), and each pest and disease attack (48 per cent), no availability of labour during peak period (43 per cent) and certified seed availability not at the appropriate time was (30 per cent). Among large farmers, the major constraint was high prices of certified seed (78 per cent), no public procurement at the MSP (73 per cent), no availability of labour during peak period (70 per cent), pest and disease attack (68 per cent), the problem faced by farmers due to fluctuation in prices and high prices of insecticides and pesticides was (63 per cent) each, lack of access to extension services (60 per cent), covid related restriction (58 per cent), certified seed availability not at the appropriate time was (45 per cent). The result are also in confirmity with the study of Layek and Mula (2021). Overall, the major constraint in the Jalandhar district was high prices of certified seed (69 per cent), followed

**Table 6: Difference in yield among potato crops raised with certified and non-certified seeds in Jalandhar district**

| Particulars                                                | Small    | Medium   | Large     | Overall   |
|------------------------------------------------------------|----------|----------|-----------|-----------|
| Total no. of farmers                                       | 40 (100) | 40 (100) | 40 (100)  | 120 (100) |
| No. of farmers using both certified and non-certified seed | 4 (10)   | 7 (17.5) | 11 (27.5) | 22 (18.3) |
| Yield-Certified Seed (qtl/acre)                            | 110.5    | 118.5    | 122       | 117       |
| Yield-Non-Certified Seed (qtl/acre)                        | 99.02    | 101.4    | 110.4     | 103.6     |
| Difference in yield                                        | 16.9     | 17.1     | 11.6      | 15.2      |
| Per cent Difference                                        | 17.0     | 16.8     | 10.5      | 14.7      |
| t-value                                                    | 1.73**   | 2.28**   | 0.67**    | 1.94**    |

Source: Field Survey

**Table 7: Constraints faced by farmers of Potato seed Production in Jalandhar district (Multiple responses)**

| Constraints                                                | Small (40) | Medium (40) | Large (40) | Overall (120)    |
|------------------------------------------------------------|------------|-------------|------------|------------------|
| Non-availability of labour during peak period              | 10 (25)    | 17 (42.5)   | 28 (70)    | 55 (45.8)        |
| Fluctuation in Price of potato seed                        | 18 (45)    | 23 (57.5)   | 25 (62.5)  | 66 (55)          |
| Lack of Public Procurement at the MSP                      | 12 (30)    | 23 (57.5)   | 29 (72.5)  | 64 (53.3)        |
| The high price of certified seed                           | 25 (62.5)  | 27 (67.5)   | 31 (77.5)  | <b>83 (69.1)</b> |
| Certified seed availability is not at the appropriate time | 9 (22.5)   | 12 (30)     | 18 (45)    | 39 (32.5)        |
| Lack of access to extension services                       | 14 (35)    | 20 (50)     | 24 (60)    | 58 (48.3)        |
| High cost of insecticides and pesticides                   | 28 (70)    | 26 (65)     | 25 (62.5)  | 79 (65.8)        |
| Pest and Disease attack                                    | 15 (37.5)  | 19 (47.5)   | 27 (67.5)  | 61 (50.8)        |
| Covid related restrictions                                 | 19 (47.5)  | 21 (52.5)   | 23 (57.5)  | 63 (52.5)        |

Source: Field survey

by the high cost of insecticides and pesticides (66 per cent), fluctuation in price (55 per cent), no public procurement at the MSP (53 per cent), covid related restriction (52 per cent), pest and disease attack (51 per cent), lack of access to extension services (48 per cent), non-availability of labour during peak period (46 per cent) and certified seed availability not at the appropriate time (33 per cent). The results of the study are in close conformity with Kaur *et al* (2020) who also reported that major production constraints in seed potato crop were the high cost of insecticides, pesticides and fungicides, the high price of certified seed availability not at the appropriate time.

## CONCLUSION

The study found that only 18 per cent of selected respondents procured seeds from government agencies like CPRS (ICAR), the Centre of excellence (Dogri) and the Department of Horticulture Punjab. To reduce the dependence of potato seed growers on private agencies for seed procurement, the centre and state government should make joint efforts to increase seed production in these institutions. The overall seed replacement rate was 19.5 per cent for the potato crop, which is low. The main reason for the low seed replacement rate for potato

crops was the high cost of certified seeds. The government should spend on research and development of potato seed to increase the seed replacement rate through ICAR, PAU, and other important research institutes. The union and state governments may provide the required funds in this regard. The study further revealed that the yield of potato crops by using certified seed was higher than non-certified seed. The per cent difference in yield of potato crops grown by certified and non-certified seed among small and medium farmers was 17 per cent, 11 per cent among large farmers and 15 per cent overall in the Jalandhar district of Punjab. Extension services should be strengthened in the study area to educate the potato growers on more use of certified seeds. The study highlighted that the primary constraint faced by potato seed growers were high prices of certified sources (69.1 per cent), high cost of pesticides and insecticides (65.8 per cent), fluctuations in the price of potato seed (55 per cent), lack of public procurement at MSP (53.3 per cent), covid related restrictions (52.5 per cent) and lack of extension facilities (48.3 per cent). To combat the above-stated problems government should fix MSP for the potato crop. This ensured price of potato crop will also lead to the diversification in the state and save the state from the problems arising

from wheat paddy monoculture. Government should also provide the inputs at a subsidised rate to potato seed growers, and extension services should also be provided to the farmers for judicious use of these inputs.

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# OPTIMIZATION OF PLANTING GEOMETRY AND HAULM KILLING DAYS FOR INCREASING PRODUCTION OF SEED SIZE TUBERS IN POTATO

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**ABSTRACT:** A field experiment was conducted for two consecutive years 2018-19 and 2019-20 with high bulking early potato cultivar Kufri Khyati at Central Potato Research Institute, RS, Gwalior in split plot design with six planting geometries as main plots *viz* S<sub>1</sub>-60×20 cm (Control), S<sub>2</sub>-66×15 cm, S<sub>3</sub>-66×20 cm, S<sub>4</sub>-75 ×15 cm, S<sub>5</sub>-75×20 cm and S<sub>6</sub>-paired row and three haulm killing dates as sub plots *viz* 70, 80 and 90 days after planting. For growth parameters, only planting geometry 66×15 cm recorded significantly higher plant height (52.6 cm) over other planting geometries. 75×15 cm (52.6) and 75×20 cm (50.2) planting geometry recorded non significant but higher compound leaves/plant over other plant geometries. Days to haulm killing did not influence the growth parameters *viz*, stem, compound leaves and plant height. Significant increasing trend was recorded for number and weight of seed size and total tubers with increasing planting geometry over wider plant geometry 75×20 cm (285 thousand/ha, 17.41 t/ha seed size tuber and 671 thousand/ha, 34.52 t/ha for total tuber) and highest was recorded in paired row planting (487 thousand/ha, 29.52 t/ha seed size tuber and 1040 thousand/ha, 45.93 t/ha total tuber). Paired row planting with 70 days of haulm killing recorded significantly highest seed size (516 thousand/ha) and total tuber number (1092 thousand/ha). By number 60×20 cm planting geometry at 80 days of haulm killing (51.15% and 0.957) and by weight paired row planting at 70 days of haulm killing (73.15% and 0.367) recorded significantly highest seed size tubers percent and best seed: non seed ratio over other factor combinations. Planting geometry 66×15 cm at 80 days haulm killing (11.3) and 75×15 cm at 90 days of haulm killing (11.7) recorded significantly highest seed multiplication rate by number and weight respectively. Paired row planting with 70 days haulm killing gave highest seed size tuber yield, per cent seed size tuber and best seed: non seed ratio but planting geometry with 66×20 cm and haulm killing at 70 days found to be economically viable option for the farmers with higher B:C ratio (1.75) for seed production of variety Kufri Khyati.

**Key words:** Seed production, planting geometry, haulm killing, Potato, seed: non seed ratio

## INTRODUCTION

One of the main economic problems in the production of high-quality seed potatoes is their cost to end users. The cost of seed represents the greatest proportion of the total production cost and account for 30 to 50% of the total production expenses depending on the country or region (Kabir *et al.*, 2004; Karim *et al.*, 2010). In India this cost ranges from 40 to 50% of the total production costs (Beata 2020, Chakraborti *et al.*, 2013) and single most important factor in potato cultivation and hence good

quality seed is required for optimization of potato production (Chakraborti *et al.*, 2013). Kufri Khyati is a high yielding early maturing variety having moderate resistance to late blight, yields higher than the other early maturing cultivars and performs well both under very early (60 days) and early (75 days) harvests (Kumar *et al.*, 2009). This variety when cultivated under seed production for 70-80 days produces 43-47 % by number and 27-35 % by weight (small and large) non seed size tubers (Sadawarti *et al.*, 2017).

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Seed tuber size is an important factor to decide the seed rate per unit area because it affects total yield and graded or marketable tuber yields (Singh and Kushwah, 2010 and Dagne *et al.*, 2019). Seed rate depends on the size of tubers used in potato planting. Seed tubers of 25–125 g (30–55mm) are recommended as seed size tubers (IMSCS, 2013). Obtaining seed size tuber is important for achieving higher potential of the cultivars. The tuber size profile can be reduced or expanded by altering inter and intra row seed spacing, controlling days of growth by planting late or killing vines/haulm early, regulating inputs like fertilizer and water, applying growth regulators, and manipulating seed tuber physiological age. (Kumar *et al.*, 2009). When potatoes are grown for seed, cultural practices need to be used in order to maximize the production of seed size tubers (Sanli, 2015). Planting geometry influence yield, tuber size distribution, tuber, stem density and net returns of potato cultivars (Love and Thompson-Johns, 1999; Bussan *et al.*, 2007; Zamilet *et al.*, 2010; Nasir and Akassa, 2018 and Dawinder., 2020). Increasing the planting density may lead to a decrease in the average weight of the tuber and the percentage of the large size tubers (Love and Thompson-Johns 2006; Gasimova *et al.*, 2010; Mahmoodabad *et al.*, 2010; Somarin *et al.*, 2010). An ideal combination of plant population, row width, and in-row seed spacing for a particular variety were the major factors for optimizing tuber size and increasing grower's revenue (Rex and Mazza 1989). Planting of seed tubers on ridges is widely followed method with some modifications from place to place. As against single-row geometry of planting on each ridge, paired-row planting on ridges at different spacing has also been tested keeping constant or variable seed rates (Mishra, 2013).

Haulm/ vine killing is one of the criteria used in seed potato production primarily to regulate tuber size profile (Singh and Kushwah, 2010; Kumar *et al.*, 2009 and Virtanen and Seppänen 2014). Haulm killing is done to stop tuber growth in order to reduce tuber size and to obtain a uniform size distribution with a maximum proportion of the tubers in the most profitable size class, strengthen tuber skins, and to reduce the risk of spread of virus infection by inhibiting plant-to-plant spread through vectors such as aphids (Struik and Wiersema 1999 and Kempenaar and Struik, 2007). The highest values of tuber yield was established with planting of seed tuber sizes of 35–45 mm (de Almeida *et al.*, 2016). Appropriate seed tuber size has very important implication on potato production. The number of sprouts that develop from a seed tuber is influenced by the size of seed tuber. In larger tubers, growth is faster because of greater food reserve availability for each sprout and generally produce more sprouts which may result in the production of too many stems and eventually produce too many tubers (Dagne, 2015). If larger seed is used, a greater quantity of seed is required for planting per unit area. It is avoided because it increases seed costs and reduce planter's accuracy (Singh and Kushwah, 2010). Conversely, smaller seed size tubers have less sprouts per unit due to the lesser amount of reserves available for sprout growth leading to small number of stems that produce only a few tubers, thereby reducing yield (Dagne, 2015). Big size seed will increase cost and seed that are too small may rot before emergence (Wang, 2008). Moreover in recent time it was also observed that frequent rainfall occurs in the month of December and January before the time of haulm killing due to climate change effect which prolongs the date of haulm killing. With this background present

experiment was conducted to optimize different combinations of planting geometry and haulm killing days for increasing proportion of seed size tubers in Kufri Khyati under changing climate scenario.

## MATERIALS AND METHODS

A field experiment was conducted for two consecutive years in split plot design with high bulking early potato cultivar Kufri Khyati at Central Potato Research Institute, RS, Gwalior (26° N and 78° E, 207 m above sea level and receives annual rainfall 400–800 mm), during 2018-19 and 2019-20. The soil of the experimental field was silty clay loam having organic carbon 0.39%, available N 125, P 41 and K 330 kg ha<sup>-1</sup>, pH 7.0 and EC 0.2 dS m<sup>-1</sup>, Cu 0.9 ppm, Zn 0.94 ppm, Fe 17 ppm and Mg 0.88 ppm. Organic carbon content of soils is generally low because of high temperature in summers. Soil is heavy textured having high silt and clay contents. Treatments consisted of six planting geometry as main plot *viz* S<sub>1</sub>-60 × 20 cm (Control), S<sub>2</sub>-66 × 15 cm, S<sub>3</sub>-66 × 20 cm, S<sub>4</sub>-75 × 15 cm, S<sub>5</sub>-75 × 20 cm and S<sub>6</sub>-paired row and three haulm killing dates as sub plots *viz* 70, 80 and 90 days after planting. Well sprouted seed sized tubers weighing 40–50 g were planted in 23.10.2018 and 10.11.2019 as per geometry in plot size *viz*, S<sub>1</sub>-10.8 M<sup>2</sup>, S<sub>2</sub> and S<sub>3</sub>- 11.88 M<sup>2</sup>, S<sub>4</sub> and S<sub>5</sub>-13.5 M<sup>2</sup> and S<sub>6</sub>- 8.1 M<sup>2</sup> (Paired row). Fertilizer P and K were applied @ 60 and 100 kg ha<sup>-1</sup> respectively. Full doses of P and K and half dose of N were applied at the time of planting and remaining half dose of N was applied through urea at the time of earthing up which was done 25 days after planting (DAP). At planting, half dose of nitrogen with full dose of phosphorus and potassium were applied through ammonium sulphate, single super phosphate and muriate of potash, respectively.

Recommended seed production practices were followed during the crop growth season as mentioned in the seed plot technique. Thimet 10 G @ 10 kg/ha for controlling insects was applied at the time of earthing up and mancozeb @ 2 kg/ha sprayed as a preventive measure for late blight, leaf spot and other foliar diseases of potato. After emergence at 15–20 days interval, an alternate spray of imidacloprid @ 0.002%, triazophos@1.6 l/ha and thiamethoxam @130 g/ha was done to protect seed crop from insects. For controlling the weeds metribuzin mixed in 1000 l of water was applied @ 0.75 kg a.i. /ha. Haulm killing was done as per the schedule dates 70, 80 and 90 days after planting, respectively. Tubers were harvested 12-14 days after haulm killing on hardening of tuber skin. Observations on crop growth and yield attributes were recorded at 50 DAP and at harvest of the crop. Weekly weather data on max/min temperature, and relative humidity was recorded during crop growth in two year of experimentation and average max/min temperature and relative humidity is presented in table 1. Percent non seed size and seed size tuber, seed: non seed ratio and seed multiplication rate were calculated by following formulas

$$\text{Percent non seed tuber} = \frac{\text{Non seed size tuber yield number and weight}}{\text{Total tuber yield by number and weight}} \times 100$$

$$\text{Percent seed tuber} = \frac{\text{Seed size tuber yield by number and weight}}{\text{Total tuber yield by number and weight}} \times 100$$

$$\text{Seed: non seed ratio for number and weight} = \frac{\text{Non seed size tuber yield by number and weight}}{\text{Seed size tuber yield by number and weight}}$$

$$\text{Seed multiplication rate} = \frac{\text{Total tuber yield by number and weight/ha}}{\text{Seed rate by number and weight/ha}}$$

Data were pooled and analyzed statistically and means were separated according to the least significant differences (LSD) at 0.05 level of probability.

**Table 1** Max/min temperature and relative humidity during crop growth

| Crop period  | Temperature (Degree Celsius) |      |         |      | Relative Humidity (%) |      |         |      |
|--------------|------------------------------|------|---------|------|-----------------------|------|---------|------|
|              | 2018-19                      |      | 2019-20 |      | 2018-19               |      | 2019-20 |      |
| Week         | Max                          | Min  | Max     | Min  | Max                   | Min  | Max     | Min  |
| Oct 22-28    | 34.5                         | 14.9 | 31.5    | 14.1 | 80.7                  | 28.7 | 89.4    | 31.7 |
| Oct-Nov 29-4 | 33.3                         | 14.4 | 32      | 16.4 | 82.1                  | 28.2 | 89.0    | 42.3 |
| Nov 5-11     | 29.6                         | 10.6 | 30.8    | 14.0 | 83.6                  | 33.6 | 88.9    | 37.3 |
| Nov 12-18    | 31.6                         | 13.5 | 29.7    | 14.7 | 80.3                  | 28.3 | 84.4    | 43.1 |
| Nov 19-25    | 35.3                         | 11.4 | 28.5    | 11.0 | 88.3                  | 30.7 | 93.3    | 41.7 |
| Nov-Dec 26-2 | 26.7                         | 9.8  | 27.1    | 12.4 | 99.3                  | 39.1 | 92.0    | 52.0 |
| Dec. 3-9     | 26.8                         | 7.2  | 24.0    | 6.7  | 93.6                  | 33.3 | 94.7    | 43.3 |
| Dec 10-16    | 22.4                         | 6.8  | 21.3    | 9.5  | 90.4                  | 57.7 | 95.9    | 62.3 |
| Dec. 17-23   | 23.5                         | 4.5  | 19.2    | 4.9  | 90.7                  | 38.4 | 94.4    | 54.7 |
| Dec. 24-31   | 22.8                         | 3.5  | 13.5    | 2.3  | 94.5                  | 36.8 | 96.6    | 75.9 |
| Jan 1-7      | 24.0                         | 6.2  | 21.7    | 6.6  | 94.7                  | 46.7 | 96.3    | 59.0 |
| Jan 8-14     | 21.7                         | 5.5  | 20.4    | 5.6  | 93.6                  | 41.3 | 93.3    | 72.6 |
| Jan 15-21    | 23.8                         | 4.6  | 18.3    | 7.6  | 91.7                  | 34.9 | 96.1    | 70.7 |
| Jan 22-28    | 20.6                         | 9.0  | 22.8    | 5.2  | 92.4                  | 74.9 | 88.4    | 45.6 |
| Jan-Feb 29-4 | 20.6                         | 5.8  | 22.2    | 6.0  | 92.8                  | 58.6 | 94.0    | 56.9 |
| Feb 5-11     | 22.8                         | 9.0  | 22.4    | 4.9  | 85.6                  | 61.3 | 93.7    | 44.9 |

## RESULTS AND DISCUSSION

### Plant emergence

Planting geometry did not show significant variation for final plant emergence, but it was in the range of 86.43% in 75×15 cm to 88.64% in 60×20 cm planting geometry (table 2). Lower planting geometry recorded non significant but higher plant emergence than higher planting density in mini tuber study (Hossain *et al.*, 2015). No significant differences was recorded in 70 and 80 days of haulm killing (Singh and Singh, 2016, Sadawarti *et al.*, 2017). Among the interaction between planting geometry and days of haulm killing, no significant difference was recorded at both the parameter level. None of the interactions among intra-spacing, haulm killing dates and N doses found significant for plant emergence (Singh and Singh, 2016; Sadawarti *et al.*, 2017 and Mandal and Das, 2020)

### Growth attributing parameters

For stem/plant, planting geometry, days of haulm killing and their interactions did not show significant variation. Non significant differences were recorded for spacing combination for stems/plant (Kushwah and Singh, 2008; Akassa *et al.*, 2014; Arega *et al.*, 2018 and Mandal and Das, 2020). Singh *et al.* (2010) did not find significant difference in number of shoots under triple row, paired row and single row planting geometry with or without drip irrigation system. Similar results were recorded in present study. Only higher planting geometry 66×15 cm recorded significantly higher plant height (52.6 cm) over other planting geometries. Such increase in higher planting geometry could be attributed to increased competition among the stems for light and space as already reported by earlier workers (Barry *et al.*, 2000; Sharma *et al.*, 2013, Tesfaye *et*

Table 2 Growth parameters as influence by planting geometry and haulm killing days

| Plant geometry /<br>DOHK    | Emergence %                 |       |       |       |      | No. of stem/ plant |      |      |      |      | Plant height (Cm) |      |      |      |      | No. of compound leaves/ plant |      |      |      |      |
|-----------------------------|-----------------------------|-------|-------|-------|------|--------------------|------|------|------|------|-------------------|------|------|------|------|-------------------------------|------|------|------|------|
|                             | 70                          |       | 80    |       | 90   |                    | 70   |      | 80   |      | 90                |      | 70   |      | 80   |                               | 90   |      | 70   |      |
|                             | Days                        | Mean  | Days  | Mean  | Days | Mean               | Days | Mean | Days | Mean | Days              | Mean | Days | Mean | Days | Mean                          | Days | Mean | Days | Mean |
| 60 × 20 cm (Control)        | 86.85                       | 88.71 | 90.37 | 88.64 | 4.7  | 4.2                | 4.7  | 4.5  | 48.0 | 47.2 | 50.7              | 48.6 | 48.0 | 44.0 | 44.0 | 51.0                          | 47.7 | 48.0 | 47.2 | 48.0 |
| 66 × 15 cm                  | 86.39                       | 87.92 | 85.83 | 86.71 | 4.3  | 4.3                | 4.3  | 4.1  | 52.5 | 52.7 | 52.7              | 52.6 | 47.3 | 49.5 | 49.5 | 47.2                          | 48.0 | 47.2 | 48.0 | 48.0 |
| 66 × 20 cm                  | 89.26                       | 85.74 | 89.26 | 88.09 | 4.3  | 4.5                | 4.3  | 4.3  | 49.2 | 49.3 | 49.2              | 49.2 | 47.3 | 52.0 | 52.0 | 49.2                          | 49.5 | 49.2 | 49.2 | 49.5 |
| 75 × 15 cm                  | 86.53                       | 86.67 | 86.11 | 86.43 | 4.7  | 4.8                | 4.7  | 4.9  | 48.8 | 48.7 | 52.0              | 49.8 | 56.2 | 53.0 | 48.5 | 48.5                          | 52.6 | 48.5 | 48.5 | 52.6 |
| 75 × 20 cm                  | 86.48                       | 89.45 | 88.89 | 88.27 | 4.5  | 4.8                | 4.5  | 4.6  | 49.7 | 50.5 | 47.7              | 49.3 | 48.3 | 49.8 | 52.5 | 50.2                          | 50.2 | 49.7 | 49.7 | 49.9 |
| Paired Row                  | 86.85                       | 87.41 | 89.81 | 88.02 | 4.3  | 4.7                | 4.3  | 4.7  | 50.0 | 51.0 | 48.0              | 49.7 | 49.7 | 52.5 | 47.7 | 49.9                          | 49.9 | 49.7 | 49.7 | 49.9 |
| Mean                        | 87.06                       | 87.65 | 88.38 |       | 4.5  | 4.6                | 4.5  |      | 49.7 | 49.9 | 50.0              | 2.10 | 49.5 | 50.1 | 49.3 |                               |      |      |      |      |
| CD <sub>0.05</sub>          | Plant geometry (A)          |       |       |       |      | NS                 |      |      |      |      | NS                |      |      |      |      | NS                            |      |      |      |      |
|                             | DOHK (B)                    |       |       |       |      | NS                 |      |      |      |      | NS                |      |      |      |      | NS                            |      |      |      |      |
|                             | Factor(B)at same level of A |       |       |       |      | NS                 |      |      |      |      | NS                |      |      |      |      | NS                            |      |      |      |      |
|                             | Factor(A)at same level of B |       |       |       |      | NS                 |      |      |      |      | NS                |      |      |      |      | NS                            |      |      |      |      |
| DOHK- Days of haulm killing |                             |       |       |       |      |                    |      |      |      |      |                   |      |      |      |      |                               |      |      |      |      |

*al.*, 2013; Singh and Singh 2016; de Almeida *et al.*, 2016; Mvumi *et al.*, 2018 and Singh *et al.*, 2019). Higher planting density of 50 ×15 cm recorded significantly higher plant height over 50×20 cm and 50×25 cm (Singh *et al.*, 2019). This confirms the present study. Days to haulm killing and factor level interactions did not show any significant difference for plant height. Delayed haulm killing from 70 to 80 days and at 5 days interval from 65 days under Gwalior and from 60 to 70 and 80 days under Modipuram conditions did not show any significant difference for plant height under seed production study (Singh and Kushwah, 2009, Sadawarti *et al.*, 2017 and Kumar *et al.*, 2001).

In present study, 75×15 cm (52.6) and 75×20 cm (50.2) planting geometry recorded non significant but higher compound leaves/ plant over plant geometries. Compound leaves per plant showed a gradual and significant increase with the decreasing plant density (Singh *et al.*, 2019). Reduction in number of leaves with increasing plant population can be attributed to the availability of limited space thus posing a barrier for the proper development of plant (Lal *et al.* 1981; Khurana and Pandita 1982; Kushwah 1989 and Singh *et al.* 1997). This confirms the results of present study. Days to haulm killing did not show any significant difference for compound leaves/plant and was in the range of 49-50 compound leaves/ plant. Delayed haulm killing from 70 to 80 days under Gwalior and Patna conditions did not show any significant for leaves/plant (Singh and Singh, 2016 and Sadawarti *et al.*, 2017) confirming the present study (Table 2).

## Yield parameters

### Grade wise non seed, seed and total tubers/ha

Measurement of different grades of tubers are important for quantification of seed size

tubers under seed production programme. Under the study, seed tubers were graded in three different sizes, viz. <25 g and >125 g (non seed size), 25-125 g (seed size) as per Indian minimum seed certification standards,

#### **Non seed size tubers (<25 and >125g)**

For <25 g grade by number, all the planting geometry except 60×20 cm recorded significantly higher <25 g tubers over 75×20 cm spacing (297 thousand/ha) and highest was recorded in paired row system (480 thousand/ha). Narrower distance increases undersize and small tubers (Kushwah and Singh, 2008; Akasa *et al.*, 2014 and Mangani *et al.*, 2015; Dawinder *et al.*, 2020). This confirms the present result where closer spacing gave higher small tuber than wider spacing. The highest yield of small-sized tubers at higher planting density (paired row) might be due to the fact that higher seed- piece spacing exerted a measurable effect on the yield of small potatoes. This is in agreement with Binalfew *et al* (2015). Significant decreasing trend for <25 g tuber was recorded with delay in haulm killing days and highest was recorded in early 70 days haulm killing (387 thousand/ha) and lowest in 90 days haulm killing (338 thousand/ha). In interactions, paired row at 70 days haulm killing (541 thousand/ha) and 60×20 plant geometry at 90 days haulm killing (274 thousand/ha) recorded highest and lowest tuber number respectively (Table 2). For weight, all the planting geometry recorded significantly higher <25 g tubers over 66×20 cm spacing (2.72 t/ha) and highest was recorded in paired row system (4.46 t/ha). Similar trend was recorded for haulm killing days as tuber number. In interactions, paired row at 70 days haulm killing (5.0 t/ha) and 66×20 cm plant geometry at 90 days haulm killing (2.56 t/ha) recorded highest

and lowest tuber number, respectively (table 4).

For >125 g grade by number, only lower planting density 66×20 cm (97 thousand/ha), 75×15 cm (83 thousand/ha) and 75×20 (89 thousand/ha) recorded significantly higher tuber number over paired row planting (73 thousand/ha) table 2. This may be because of few sinks available per unit area that resulted in less competition between the individuals at low plant densities where more resources were channeled to each individual tuber resulting in a high number of large sized tubers. This is in agreement with Mangani *et al.*, 2015. Yield both by number and weight of small sized tubers and total tubers increased significantly with closer plant spacing, while the yield of bigger size tubers increased with wider planting geometry (Kumar *et al.*, 2001; Kumar and Lal, 2006; Singh and Singh, 2016) irrespective of varieties (Mangani *et al.*, 2015). In present study, decrease in total number of tubers and increase in the proportion of large-sized tubers size with increase in intra-row spacing are in accord with the observations of Kumar *et al.*, 2001.

80 days (86 thousand/ha) and 90 days (110 thousand/ha) haulm killing recorded significantly higher >125 g tuber number over 70 days haulm killing (53 thousand/ha). Similar results were reported with 10 days delayed haulm killing from 60 to 70 and 80 days by Kumar *et al.*, 2001. In factor interaction, 66×20 cm plant geometry with 90 days haulm killing (123 thousand/ha) recorded highest and paired row at 70 days haulm killing (35 thousand/ha) lowest over sized tuber number (table 2). For weight, only 75×20 (13.61 t/ha) recorded significantly higher tuber weight over 66×20 cm planting (11.92 t/ha) and other planting geometries were at par. Eighty days (12.76 t/ha) and 90 days (16.20/ha) haulm killing recorded

Table 3 Grade-wise seed tuber number (000/ha) as influenced by planting geometry and haulm killing days

| Plant geometry/<br>DOHK     | Non seed size               |            |            |       |            |            | Seed size  |      |            |            |            |      | Total      |            |            |      |
|-----------------------------|-----------------------------|------------|------------|-------|------------|------------|------------|------|------------|------------|------------|------|------------|------------|------------|------|
|                             | <25g                        |            |            | >125g |            |            | 25-125g    |      |            |            |            |      |            |            |            |      |
|                             | 70<br>Days                  | 80<br>Days | 90<br>Days | Mean  | 70<br>Days | 80<br>Days | 90<br>Days | Mean | 70<br>Days | 80<br>Days | 90<br>Days | Mean | 70<br>Days | 80<br>Days | 90<br>Days |      |
| 60× 20 cm (Control)         | 344                         | 319        | 274        | 312   | 58         | 71         | 106        | 78   | 409        | 407        | 391        | 402  | 806        | 787        | 775        | 789  |
| 66×15 cm                    | 378                         | 360        | 438        | 392   | 59         | 74         | 100        | 78   | 455        | 446        | 441        | 448  | 892        | 880        | 979        | 917  |
| 66× 20 cm                   | 368                         | 367        | 328        | 355   | 60         | 108        | 123        | 97   | 391        | 382        | 378        | 384  | 819        | 858        | 829        | 835  |
| 75 ×15 cm                   | 367                         | 330        | 304        | 334   | 42         | 96         | 112        | 83   | 358        | 347        | 352        | 352  | 767        | 773        | 767        | 769  |
| 75× 20 cm                   | 322                         | 293        | 277        | 297   | 64         | 88         | 113        | 89   | 328        | 270        | 257        | 285  | 714        | 651        | 647        | 671  |
| Paired Row                  | 541                         | 492        | 407        | 480   | 35         | 80         | 104        | 73   | 516        | 472        | 473        | 487  | 1092       | 1044       | 984        | 1040 |
| Mean                        | 387                         | 360        | 338        |       | 53         | 86         | 110        |      | 409        | 387        | 382        |      | 848        | 832        | 830        |      |
| CD <sub>0.05</sub>          | Plant geometry (A)          |            |            | 24.3  |            |            |            | 6.6  |            |            |            | 29.4 |            |            |            | 29.0 |
|                             | DOHK (B)                    |            |            | 12.1  |            |            |            | 3.2  |            |            |            | 10.8 |            |            |            | NS   |
|                             | Factor(B)at same level of A |            |            | 30.8  |            |            |            | 8.1  |            |            |            | 27.8 |            |            |            | 42.5 |
|                             | Factor(A)at same level of B |            |            | 34.2  |            |            |            | 9.1  |            |            |            | 36.4 |            |            |            | 44.4 |
| DOHK- Days of haulm killing |                             |            |            |       |            |            |            |      |            |            |            |      |            |            |            |      |

DOHK- Days of haulm killing

one and half times and twice respectively significantly higher >125 g tuber weight over 70 days haulm killing (8.12 t/ha). Significantly higher over size tubers were recorded with 80 days haulm cut (9.65 t ha<sup>-1</sup>) over 70 days haulm cut (7.00 t ha<sup>-1</sup>) Sadawarti *et al.*, 2017. Significant interactions were recorded at factor level combinations and 75×20 cm plant geometry at 90 days haulm killing (17.74 t/ha) recorded highest and paired row at 70 days haulm killing (5.81 t/ha) lowest over size tuber weight (table 4). This confirms that wider plant geometry with delayed haulm killing increases proportion of oversize tubers. Hence 70 days haulm killing found best with minimum proportion of oversize tubers in the present study

### Seed size tubers (25-125g)

Seed size tubers (25-125 g) are very important for use as seed tubers in the successive crop season (Sadawarti *et al.*, 2019). In present study, significantly higher seed size tuber number was recorded all the other planting geometries over wider planting geometry 75×20 cm (285 thousand/ha) and highest was recorded in paired row (487 thousand/ha) followed by 66×15 cm (448 thousand/ha) table 3 and fig 1. Sadawarti *et al.*, 2017 reported that significantly higher seed size (405000 ha<sup>-1</sup>) and total tuber (702000 ha<sup>-1</sup>) number with closer intra row spacing of 15 cm over 20 cm intra-row spacing (337000 ha<sup>-1</sup> seed size and 605000 ha<sup>-1</sup> total tuber). Medium-sized seed tubers increased as spacing reduced, closer spacing of 50 cm × 25 cm and 60 cm × 25 cm produced higher medium size tuber number over wider spacings of 80 cm × 30 cm and 75 cm × 30 cm (Binalfewil *et al.*, 2015). In present study, 70 days haulm killing recorded significantly higher seed size tuber (409 thousand/ha) over 80 and 90 days of haulm killing which were at par with each other table 3 and fig 3.

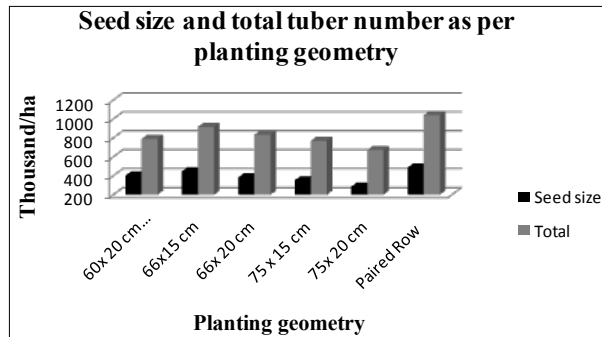


Fig 1 Seed size and total tuber number (thousand/ha) as per planting geometry

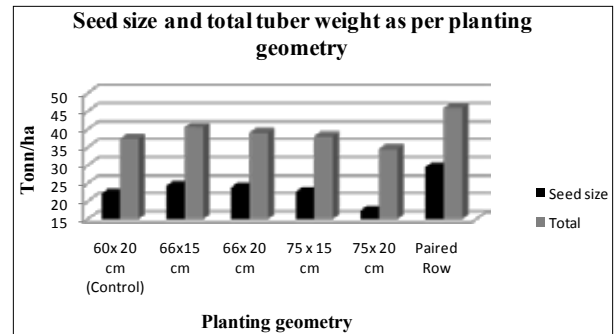


Fig 2 Seed size and total tuber weight (t/ha) as per planting geometry

The yield of small sized tubers reduced by 3.0 q/ha with an increase in crop duration by ten days (Kumar and Lal, 2006). Highest plant geometry paired row planting with 70 days of haulm killing (516 thousand/ha) and lowest planting geometry 75×20 cm at 90 days haulm killing (257 thousand/ha) recorded significantly highest and lowest seed size tubers over other factor combinations (table 3). Non-significant but highest seed size tuber number (432 thousand ha<sup>-1</sup> and 427 thousand ha<sup>-1</sup>) was recorded in 15 cm intra-row spacing×80 days haulm killing×150 kg N and 15 cm intra-row spacing×70 days haulm killing×120 kg N respectively (Sadawarti *et al.*, 2017).

For weight similar increasing trend with increasing planting geometry as of tuber number was recorded and highest was in paired row planting (29.52 t/ha) table 4 and fig 2. Sadawarti *et al.*, 2017 reported significantly higher seed size (22.44 t ha<sup>-1</sup>) tuber yield with closer intra row spacing of 15 cm over 20 cm intra-row spacing (19.81 t ha<sup>-1</sup> seed size). Similar result were obtained in closer spacing of 50×10 cm under Bangladesh conditions (Al Mamun *et al.*, 2016). But for haulm killing days reverse trend of tuber number was recorded for seed size tuber weight and 80 (23.48 t/ha) and 90 days haulm killing (24.12 t/ha) recorded significant increase in tuber weight over 70

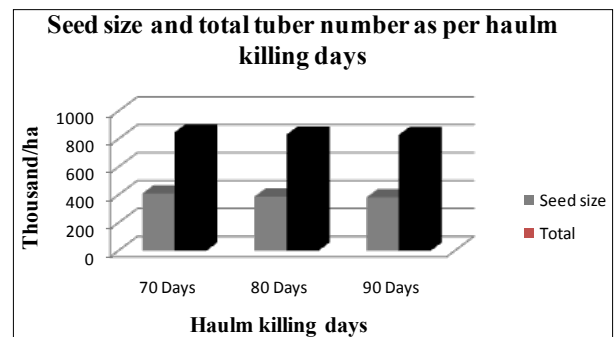


Fig 3 Seed size and total tuber number (thousand/ha) as per haulm killing days

days (22.39 t/ha) haulm killing days (table 4 and fig 4). All other factor combinations were significantly higher tuber weight over 75×20 cm planting geometry at 70, 80 and 90 days haulm killing. Paired row planting recorded highest seed size tubers over other combinations with non-significant

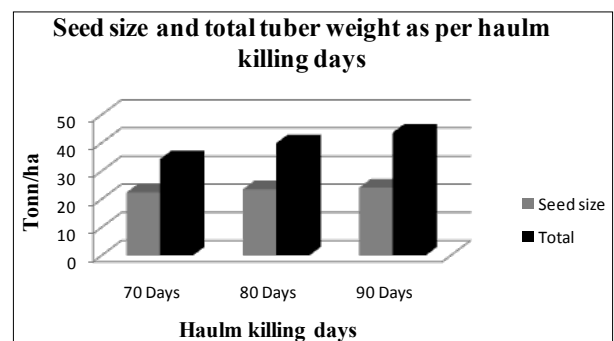


Fig 4 Seed size and total tuber weight (t/ha) as per haulm killing days

Table 4 Grade-wise and total seed tuber weight (t/ha) as influenced by planting geometry and haulm killing days

| Plant geometry/<br>DOHK | Non seed size               |            |            |       |            |            | Seed size  |       |            |            |            |       | Total      |            |            |       |  |
|-------------------------|-----------------------------|------------|------------|-------|------------|------------|------------|-------|------------|------------|------------|-------|------------|------------|------------|-------|--|
|                         | <25g                        |            |            | >125g |            |            | 25-125g    |       |            |            |            |       |            |            |            |       |  |
|                         | 70<br>Days                  | 80<br>Days | 90<br>Days | Mean  | 70<br>Days | 80<br>Days | 90<br>Days | Mean  | 70<br>Days | 80<br>Days | 90<br>Days | Mean  | 70<br>Days | 80<br>Days | 90<br>Days | Mean  |  |
| 60 ×20 cm (Control)     | 3.09                        | 3.57       | 2.95       | 3.20  | 8.58       | 10.61      | 16.57      | 11.92 | 20.43      | 24.19      | 22.03      | 22.22 | 32.10      | 38.38      | 41.55      | 37.34 |  |
| 66×15 cm                | 3.52                        | 3.86       | 4.60       | 4.00  | 9.28       | 12.58      | 15.07      | 12.31 | 21.66      | 24.87      | 26.23      | 24.25 | 34.46      | 41.31      | 45.90      | 40.56 |  |
| 66×20 cm                | 2.64                        | 2.95       | 2.56       | 2.72  | 8.84       | 12.69      | 15.64      | 12.39 | 22.69      | 24.03      | 24.93      | 23.88 | 34.17      | 39.68      | 43.13      | 38.99 |  |
| 75 × 15 cm              | 3.74                        | 3.40       | 3.01       | 3.38  | 6.75       | 13.27      | 15.91      | 11.98 | 22.70      | 21.97      | 23.45      | 22.71 | 33.20      | 38.64      | 42.38      | 38.07 |  |
| 75× 20 cm               | 4.00                        | 3.43       | 3.08       | 3.50  | 9.45       | 13.63      | 17.74      | 13.61 | 17.37      | 16.88      | 17.98      | 17.41 | 30.82      | 33.94      | 38.80      | 34.52 |  |
| Paired Row              | 5.00                        | 4.65       | 3.73       | 4.46  | 5.81       | 13.78      | 16.26      | 11.95 | 29.51      | 28.95      | 30.11      | 29.52 | 40.32      | 47.38      | 50.10      | 45.93 |  |
| Mean                    | 3.67                        | 3.64       | 3.32       |       | 8.12       | 12.76      | 16.20      |       | 22.39      | 23.48      | 24.12      |       | 34.18      | 39.89      | 43.64      |       |  |
| CD <sub>0.05</sub>      | Plant geometry (A)          |            |            | 0.275 |            |            |            | 0.828 |            |            |            | 1.497 |            |            |            | 1.261 |  |
|                         | DOHK (B)                    |            |            | 0.140 |            |            |            | 0.389 |            |            |            | 0.592 |            |            |            | 0.751 |  |
|                         | Factor(B)at same level of A |            |            | 0.357 |            |            |            | 0.993 |            |            |            | 1.523 |            |            |            | NS    |  |
|                         | Factor(A)at same level of B |            |            | 0.392 |            |            |            | 1.135 |            |            |            | 1.907 |            |            |            | NS    |  |

DOHK- Days of haulm killing

DOHK- Days of haulm killing

difference at 70, 80 and 90 days haulm killing (table 4).Significantly higher yield as well as number of seed size tubers was recorded at narrow spacing (60 × 15 cm) and longer crop duration (haulm cutting at 80 days) in comparison to wider spacing and shorter crop duration (Singh and Singh, 2016). Similar trend was reported in present study.

### Total tubers

Similar significant increasing trend like seed size tuber number and weight was recorded with increasing planting geometry for total tuber number and weight over lowest plant geometry 75×20 cm and highest was recorded in paired row planting (1040 thousand/ha and 45.93 t/ha) table 3 and fig 1. This might be due to the higher number of plants produced at closer plant geometry resulting in higher sinks and efficient use of available soil nutrients and other growth factors and ground being covered with green leaves earlier (earlier in the season, light is intercepted and used for assimilation), fewer lateral branches being formed and tuber growth starting earlier in plants grown at closer plant spacing than plants at wider spacing which led to the production of highest number of total tubers per hectare. This is in agreement with Zebeay *et al.*, 2015; Mangani *et al.*, 2015; Arega *et al.*, 2018; Dagne *et al.*, 2019 and Mvumi *et al.*, 2018. Tuber yield in paired row planting was almost 40.0% higher than that in single-row planting at 60 × 20 cm spacing and about 85% more than that obtained in single-row planting at 45 × 15 cm spacing (Mishra, 2013). Mishra and Pandey, 2016 reported paired row planting geometry accompanied with furrow irrigation system was found to be the best cultural combination for tuber yield (35.2 t/ha). It appeared that plant population was major factor of increased tuber yield in case of paired-row planting. This confirms the

results of present study where higher tuber yield and number of tubers were obtained with paired row planting with furrow irrigation having highest plant population. Higher planting density resulted in higher mini tubers number per M<sup>2</sup> (Dimante and Gaile, 2015). Higher density of 60×10 cm (1247 thousand/ha) and 60 × 12.5 cm (1029 thousand/ha) recorded higher tuber number and tuber number decreased with wider intra row spacing but non-significant increase was reported in terms of tuber weight (Kushwah and Singh, 2008).

Highest yield at the closest spacing might have been due to the presence of the greatest number of plants. Foliage coverage increased with an increase in the plant density which was found to be related to higher tuber yield (Bremner and Radley, 1966). Mahmud *et al.* (2012) reported closer spacing increased the yield and that a higher foliage coverage percentage increased the yield by increasing the leaf area index and the photosynthetic area which favors production and the accumulation of more photosynthates in the tuber. Similar trend was observed by Rostami *et al.* (2015). In the present study increase in number of tubers per unit area with increasing plant population may be due to more number of plants or stems per unit area as tuber number is known to be directly related to stem number. Similar results were reported by Kushwah and Singh 2008; Malik *et al.*, 1999; Zamil *et al.*, 2010 and Singh *et al.*, 2019. Reducing the intra-row spacing significantly increased plant population and subsequently increased the yield performance (Masarirambi *et al.*, 2012 and Singh and Singh, 2016).

For total tuber number/ha no significant difference was recorded among days to haulm killing (table 3 and fig 3), but for weight significantly increasing trend was recorded with delay in haulm killing where

80 days (39.89 t/ha) and 90 days (43.64 t/ha) haulm killing recorded significantly higher tuber weight over 70 days haulm killing (34.18 t/ha) table 4 and fig 4. Similar trend with regard to total tuber number was reported by Kushwah and Singh, 2008 and Mahmud *et al.*, 2009 when haulm killing was done at 5 days interval and by Kumar *et al.* 2001 when haulm killing was done at 10 days interval from 60 to 70 and 80 days. Total tuber yield as well as processing grade yield increased significantly as the crop duration was increased from 70 to 90 days (Sandhu *et al.*, 2012). A significant increase was recorded in the yield of seed size, large size and total tubers with the increase of crop duration from 70 to 80 days (Garg *et al.*, 1999 and Singh and Singh, 2016). In interaction, All other factor combinations recorded significant increase in total tuber number over 75×20 cm plant geometry at 3 haulm killing days and highest was recorded in paired row planting with 70 days haulm killing (1092 thousand/ha).

### Per cent non seed and seed size tubers

In terms of *non seed* tuber percentage by number, significantly increasing trend was reported with decrease in planting geometry and significantly highest was recorded in 75×20 cm plant geometry (57.62%) over lowest 60×20 cm plant geometry (49.25%). Significant increase in non seed size tuber was recorded with delay in haulm killing 80 days (53.69%) and 90 days (54.17%) over 70 days haulm killing (51.54%). Similar trend was reported by Mahmud *et al.*, 2009 wherein 65 days of haulm killing recorded significantly lowest nonseed tuber (28%) and highest in 80 days of planting (37.0%). In factor combinations, 75×20 cm plant geometry at 90 days haulm killing (60.25%) recorded significantly highest non seed size tubers over other factor combinations. For weight also similar trend was recorded as of number and significantly highest and lowest non seed

size tuber were reported in 75×20 cm plant geometry (49.20%) and paired row system (35.22%), respectively. Similar trend for haulm killing days and factor combinations was recorded for weight as of tuber number percent (table 5).

Increasing planting geometry increased the percent seed size tuber both in number and weight and highest was recorded in 60×20 cm plant geometry (50.75%) by number and paired row system (64.78%) by weight. Percent production of seed size tubers to total tubers (both on weight as well as number basis) was higher at narrow intra row spacing (Singh and Singh, 2016). Delay in haulm killing decreased the seed size % tuber both by number and weight and highest was reported in early 70 days haulm killing (48.16% by number and 65.12% by weight). The percentage of seed yield was 72% for 65 days after planting with significant decrease with delay in harvesting and least 63% at 80 days harvesting (Mahmud *et al.*, 2009). In factor level combinations, 60×20 cm plant geometry at 80 days haulm killing (51.15%) by number and paired row at 70 days haulm killing (73.15%) recorded highest seed size tuber percent over other factor combinations (table 4). Increasing plant density resulted in a gradual and significant reduction in the proportion of extra-large tubers, while increasing the proportion of seed size tubers (Singh *et al.*, 2019). This confirms the present finding where high density paired row planting gave highest seed size tuber percent.

### Seed: non seed ratio

In present study, with increasing planting geometry seed: non seed ratio was better and best was recorded in 60×20 cm plant geometry (0.972) by number and paired row (0.556) by weight over lowest planting geometry 75×20 cm. Increase in plant density

Table 5 Percent non seed and seed tubers as influenced by planting geometry and haulm killing days

| Plant geometry/<br>DOHK     | By Number                     |         |         |                     |         |         | By weight               |       |         |                     |         |       |       |       |       |       |
|-----------------------------|-------------------------------|---------|---------|---------------------|---------|---------|-------------------------|-------|---------|---------------------|---------|-------|-------|-------|-------|-------|
|                             | Percent Non seed tubers       |         |         | Percent seed tubers |         |         | Percent Non seed tubers |       |         | Percent seed tubers |         |       |       |       |       |       |
|                             | 70 Days                       | 80 Days | 90 Days | Mean                | 70 Days | 80 Days | 90 Days                 | Mean  | 70 Days | 80 Days             | 90 Days | Mean  |       |       |       |       |
| 60 × 20 cm (Control)        | 49.63                         | 48.85   | 49.27   | 49.25               | 50.37   | 51.15   | 50.73                   | 50.75 | 36.35   | 36.92               | 46.98   | 40.08 | 63.65 | 63.08 | 53.02 | 59.92 |
| 66 × 15 cm                  | 48.99                         | 49.40   | 54.95   | 51.11               | 51.01   | 50.60   | 45.05                   | 48.89 | 37.19   | 39.82               | 42.86   | 39.96 | 62.81 | 60.18 | 57.14 | 60.04 |
| 66 × 20 cm                  | 52.35                         | 55.42   | 54.45   | 54.07               | 47.65   | 44.58   | 45.55                   | 45.93 | 33.63   | 39.41               | 42.23   | 38.42 | 66.37 | 60.59 | 57.77 | 61.58 |
| 75 × 15 cm                  | 53.20                         | 55.12   | 54.18   | 54.17               | 46.80   | 44.88   | 45.82                   | 45.83 | 31.59   | 43.17               | 44.65   | 39.80 | 68.41 | 56.83 | 55.35 | 60.20 |
| 75 × 20 cm                  | 54.09                         | 58.53   | 60.25   | 57.62               | 45.91   | 41.47   | 39.75                   | 42.38 | 43.66   | 50.26               | 53.68   | 49.20 | 56.34 | 49.74 | 46.32 | 50.80 |
| Paired Row                  | 52.78                         | 54.82   | 51.95   | 53.18               | 47.22   | 45.18   | 48.05                   | 46.82 | 26.85   | 38.91               | 39.90   | 35.22 | 73.15 | 61.09 | 60.10 | 64.78 |
| Mean                        | 51.84                         | 53.69   | 54.17   |                     | 48.16   | 46.31   | 45.83                   |       | 34.88   | 41.42               | 45.05   |       | 65.12 | 58.58 | 54.95 |       |
| CD <sub>0.05</sub>          | Plant geometry (A)            |         |         | 2.718               |         |         |                         | 2.719 |         |                     |         | 2.511 |       |       |       | 2.512 |
|                             | DOHK (B)                      |         |         | 0.857               |         |         |                         | 0.858 |         |                     |         | 0.845 |       |       |       | 0.845 |
|                             | Factor (B) at same level of A |         |         | 2.225               |         |         |                         | 2.225 |         |                     |         | 2.188 |       |       |       | 2.188 |
|                             | Factor (A) at same level of B |         |         | 3.212               |         |         |                         | 3.212 |         |                     |         | 3.025 |       |       |       | 3.025 |
| DOHK- Days of haulm killing |                               |         |         |                     |         |         |                         |       |         |                     |         |       |       |       |       |       |

resulted in a significant reduction in the proportionate yield of oversize tubers and improved large, seed size and under-size tuber yield at higher plant populations (Singh *et al.*, 2019). 70 days haulm killing recorded significantly best seed: noon seed ratio both for number (1.081) and weight (0.547) over poorest 80 and 90 days of haulm killing. The best ratio of seed and non-seed was 1:0.318 for 70 DAP and the poorest was 1:0.583 for 80 DAP (Mahmud *et al.*, 2009). In factor level combinations, 60×20 cm plant geometry at 70 days haulm killing (0.957) by number and paired row at 70 days haulm killing (0.367) recorded best seed: noon seed ratio over other factor combinations (table 6).

### Seed multiplication rate (SMR)

Variations in SMR was recorded among planting geometry and for number, all the planting geometries recorded significantly higher SMR over 75×15 cm planting geometry (8.7) and highest was recorded in 66×20 cm planting geometry (11.0) table 6. For weight, all the planting geometries except paired row planting recorded significantly higher SMR over 66×15 cm planting geometry (8.0) and highest was recorded in 75×20 cm planting geometry (10.4). Wider spacing contributes the increase number and weight of tuber per plant and vice versa due to higher amount of reserve food and interplant competition for space, light, water and nutrient is less in the wider spacing (Hossain *et al.*, 2015). Wider spacing significantly increased SMR both by number and weight than narrow spacing (Kumar and Lal, 2006, Singh and Singh, 2016). Increased planting density showed a significant increase of progeny minitubers number per M<sup>2</sup>, but it led to reduced multiplication rates (number of minitubers per planted plant) simultaneously (Dimante and Gaile, 2015). This confirms the present study. Significant decreasing trend

Table 6 Seed: non seed ratio and seed multiplication rate as influenced planting geometry and haulm killing days

| Plant geometry/<br>DOHK       | Seed: non seed ratio |         |         |       |       |           |         |         |       |      | Seed multiplication rate |         |         |      |      |           |         |         |       |      |
|-------------------------------|----------------------|---------|---------|-------|-------|-----------|---------|---------|-------|------|--------------------------|---------|---------|------|------|-----------|---------|---------|-------|------|
|                               | By Number            |         |         |       |       | By weight |         |         |       |      | By Number                |         |         |      |      | By weight |         |         |       |      |
|                               | 70 Days              | 80 Days | 90 Days | Mean  | Days  | 70 Days   | 80 Days | 90 Days | Mean  | Days | 70 Days                  | 80 Days | 90 Days | Mean | Days | 70 Days   | 80 Days | 90 Days | Mean  | Days |
| 60 × 20 cm (Control)          | 0.987                | 0.957   | 0.973   | 0.972 | 0.573 | 0.587     | 0.587   | 0.887   | 0.682 | 9.7  | 9.6                      | 9.3     | 9.3     | 9.5  | 7.7  | 9.2       | 9.2     | 10.0    | 9.0   |      |
| 66 × 15 cm                    | 0.963                | 0.983   | 1.220   | 1.056 | 0.597 | 0.667     | 0.750   | 0.750   | 0.671 | 8.8  | 8.7                      | 9.7     | 9.7     | 9.1  | 6.8  | 8.2       | 8.2     | 9.1     | 8.0   |      |
| 66 × 20 cm                    | 1.100                | 1.247   | 1.197   | 1.181 | 0.507 | 0.650     | 0.733   | 0.733   | 0.630 | 10.8 | 11.3                     | 10.9    | 10.9    | 11.0 | 9.0  | 10.5      | 10.5    | 11.4    | 10.3  |      |
| 75 × 15 cm                    | 1.140                | 1.230   | 1.183   | 1.184 | 0.463 | 0.760     | 0.810   | 0.810   | 0.678 | 8.6  | 8.7                      | 8.6     | 8.6     | 8.7  | 7.5  | 8.7       | 8.7     | 9.5     | 8.6   |      |
| 75 × 20 cm                    | 1.180                | 1.413   | 1.520   | 1.371 | 0.777 | 1.013     | 1.160   | 1.160   | 0.983 | 10.7 | 9.8                      | 9.7     | 9.7     | 10.1 | 9.3  | 10.2      | 10.2    | 11.7    | 10.4  |      |
| Paired Row                    | 1.117                | 1.213   | 1.083   | 1.138 | 0.367 | 0.637     | 0.663   | 0.663   | 0.556 | 9.8  | 9.4                      | 8.9     | 8.9     | 9.4  | 7.3  | 8.5       | 8.5     | 9.0     | 8.3   |      |
| Mean                          | 1.081                | 1.174   | 1.196   | 1.125 | 0.547 | 0.719     | 0.834   | 0.834   | 0.666 | 9.8  | 9.6                      | 9.5     | 9.5     | 9.4  | 7.9  | 9.2       | 9.2     | 10.1    |       |      |
| CD <sub>0.05</sub>            |                      |         |         | 0.125 |       |           |         |         | 0.066 |      |                          |         |         | 0.32 |      |           |         |         | 0.305 |      |
| DOHK (B)                      |                      |         |         | 0.037 |       |           |         |         | 0.023 |      |                          |         |         | 0.20 |      |           |         |         | 0.186 |      |
| Factor (B) at same level of A |                      |         |         | 0.096 |       |           |         |         | 0.061 |      |                          |         |         | 0.50 |      |           |         |         | NS    |      |
| Factor (A) at same level of B |                      |         |         | 0.145 |       |           |         |         | 0.081 |      |                          |         |         | 0.51 |      |           |         |         | NS    |      |
| DOHK- Days of haulm killing   |                      |         |         |       |       |           |         |         |       |      |                          |         |         |      |      |           |         |         |       |      |

Table 7 Economics as influenced planting geometry and haulm killing days

| Plant geometry/<br>DOHK     | Number<br>of tuber<br>planted/<br>ha | 70 days         |                                   |                            |                          | 80 days      |                 |                                   |                            | 90 days                  |              |                 |                                   |                            |                          |              |
|-----------------------------|--------------------------------------|-----------------|-----------------------------------|----------------------------|--------------------------|--------------|-----------------|-----------------------------------|----------------------------|--------------------------|--------------|-----------------|-----------------------------------|----------------------------|--------------------------|--------------|
|                             |                                      | Yield<br>(q/ha) | Cost of<br>cultivation<br>(₹/ ha) | Gross<br>return<br>(₹/ ha) | Net<br>return<br>(₹/ ha) | B:C<br>ratio | Yield<br>(q/ha) | Cost of<br>cultivation<br>(₹/ ha) | Gross<br>return<br>(₹/ ha) | Net<br>return<br>(₹/ ha) | B:C<br>ratio | Yield<br>(q/ha) | Cost of<br>cultivation<br>(₹/ ha) | Gross<br>return<br>(₹/ ha) | Net<br>return<br>(₹/ ha) | B:C<br>ratio |
| 60 × 20 cm<br>(Control)     | 83333                                | 321.00          | 290984                            | 481500                     | 190516                   | 1.65         | 383.80          | 321130                            | 575700                     | 254570                   | 1.79         | 415.50          | 331547                            | 623250                     | 291703                   | 1.88         |
| 66 × 15 cm                  | 101010                               | 344.60          | 317626                            | 516900                     | 199274                   | 1.63         | 413.10          | 345855                            | 619650                     | 273795                   | 1.79         | 459.00          | 363960                            | 688500                     | 324540                   | 1.89         |
| 66 × 20 cm                  | 75758                                | 341.70          | 293603                            | 512550                     | 218947                   | 1.75         | 396.80          | 317946                            | 595200                     | 277254                   | 1.87         | 431.30          | 329175                            | 646950                     | 317775                   | 1.97         |
| 75 × 15 cm                  | 88889                                | 332.00          | 302844                            | 498000                     | 195156                   | 1.64         | 386.40          | 326984                            | 579600                     | 252616                   | 1.77         | 423.80          | 339054                            | 635700                     | 296646                   | 1.87         |
| 75× 20 cm                   | 66667                                | 308.20          | 271972                            | 462300                     | 190328                   | 1.70         | 339.40          | 285814                            | 509100                     | 223286                   | 1.78         | 388.00          | 315412                            | 582000                     | 266588                   | 1.85         |
| Paired<br>Row               | 111111                               | 403.20          | 351032                            | 604800                     | 253768                   | 1.72         | 473.80          | 379870                            | 710700                     | 330830                   | 1.87         | 501.00          | 396122                            | 751500                     | 355378                   | 1.90         |
| DOHK- Days of haulm killing |                                      |                 |                                   |                            |                          |              |                 |                                   |                            |                          |              |                 |                                   |                            |                          |              |

DOHK- Days of haulm killing

was recorded for SMR by number and vice versa by weight with delay in haulm killing days (table 5). For factor level combinations, 66×20 cm planting geometry at 80 days of haulm killing (11.3) by number and 75×20 cm planting geometry at 90 days of haulm killing (11.7) by weight recorded significantly higher SMR over other combinations.

## Economics

Highest cost of cultivation (₹ 351032, ₹379870 and ₹396122 /ha) was recorded with paired row planted crop due to higher seed cost higher requirement of labor for harvesting, transport charges and old gunny bags cost which also recorded highest gross return ((₹ 604800, ₹710700 and ₹751500 /ha for 70, 80 and 90 days of haulm killing) on account of higher seed tuber yield (table 7). Higher cost of planting material (Azimuiddin *et al.*, 2009) and increased cost of cultural practices were main cause of high cost of potato cultivation. Singh *et al* (2017) also reported highest gross return of ₹ 228,900/ ha with 30<sup>th</sup> October planted crop in Kufri Khyati on account of higher tuber yield in table potato crop in 90 days harvest crop. Similar treatment combination paired row planting with 70, 80 and 90 days of haulm killings) recorded highest net return ₹253768, ₹330830 and ₹355378 respectively. The lower net returns in other planting geometries are on account of lower yields. But highest B:C ratio was recorded in 66×20 cm planting geometry 1.75, 1.87 and 1.97 in 70, 80 and 90 days of haulm killing which is mainly due to lower seed rate thereby lower seed cost and comparatively higher seed yield over other treatments after paired row and 60×20 cm planting geometry. Highest B:C ratio of 2.4 was recorded with 60×20 spacing combination in Kufri Khyati in 90 day table potato crop (Singh *et al* 2017).

## CONCLUSION

Among six planting geometry and three haulm killing days, though paired row planting with 70 days haulm killing gave highest seed size tuber yield, per cent seed size tuber by weight and best seed: non seed ratio and but in present investigation for seed production of variety Kufri Khyati planting geometry with 66×20 cm and haulm killing at 70 days found to be economically viable option for the farmers with higher B:C ratio (1.75).

## CONFLICTS OF INTEREST

The authors confirm that this manuscript has no conflicts of interest

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# ECONOMICS AND RESURGENCE OF SUCKING INSECT PESTS OF POTATO AGAINST INSECTICIDES IN NORTHERN INDIA

Anuj Bhatnagar\* and S. Subhash

**ABSTRACT:** Field experiments were conducted to record the economics, incidence and resurgence effect of commonly used insecticides like imidacloprid, thiamethoxam and oxydemeton- methyl against whitefly, *Bemisia tabaci* (Gennadius) and leafhoppers *Amrasca biguttula biguttula* Isida on early planted potato (K. Pukhraj) crop during two consecutive years 2018 and 2019. The population of *B. tabaci* and *A. biguttula biuguttula* was active on potato crop throughout the crop growth. No resurgence of whitefly and leafhopper was noticed after the application of recommended and slightly higher doses of Imidacloprid 17.8 SL and Thiamethoxam 25% WG except its sub lethal doses. While Oxydemeton- Methyl 25 EC sprayed crop showed high degree of resurgence during both the years. Highest pooled mean tuber yield (21.81 t/ha) with maximum (14.91 %) increase in tuber yield was recorded from Thiamethoxam 25% WG @ 7g/10l four sprays treated plots. The sub lethal doses of imidacloprid and thiamethoxam and all the doses of oxydemeton- methyl were recorded negative and no increase in potato yield over control. Similarly, thiamethoxam 25% WG @ 7g/10l treated plot ranked first indicating the maximum return of Rs. 2.99 per rupee invested followed by imidacloprid 17.8 SL@6 ml/10l with Rs.2.09.

**KEYWORDS:** Potato, whiteflies, leafhoppers, insecticides, economics, resurgence

## INTRODUCTION

The chaotic uses of unauthentic pesticides either low dosing or overdosing, improper applications, and repeated uses of the same group of insecticides lead to the development of resistance against most of the commonly used insecticides through natural selection pressure (Ghosal and Chatterjee, 2018). Similarly, pest resurgence is one of the important aspects related to indiscriminate use of these pesticides (Jayaraj and Regupathy, 1986). Beside the use of pesticides no other potent pest management option is still able to produce a quick knock down effect against insect vector population buildup on potato crop. Therefore, farmers are using different pesticides without proper care as per its appropriate doses in field conditions, resulting in resistance, resurgence and residues in the agro ecosystem. Potato (*Solanum tuberosum* Linn.) is an important cash

crop in India. It is cultivated under different eco-environmental conditions for local consumption and also available throughout the year (Rana and Pandey, 2007). The 53.02 million tonnes of potato is presently produced from 2.16 million ha area with an average productivity of 24.54 t/ha (Annual report, 2019). A complex of sucking pests used to infest the crop during crop growth. The leafhoppers and whitefly are most important among them due to sucking the sap directly from tender parts and transmitting important viral diseases, resulting in degeneration of potato. Whitefly is already established as an important vector and transmitting apical leaf curl virus in potato especially in Western India (Bhatnagar, 2007; Bhatnagar, 2008; Chandel *et al.* 2013 and Bhatnagar, 2013). Several insecticides belonging to different groups, mainly chlorinated hydrocarbons, organophosphate and pyrethroids have been recommended for their control but

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farmers generally complain after effectiveness of these insecticides against *whitefly* and *leafhoppers* on potato crop. It was perhaps due to continuous use of these insecticides resulting in the development of resistance and sometime resurgence against these conventional insecticides (Thakur *et al.*, 1991, Singh and Gupta, 1993). Insecticide resistance and resurgence of the most commonly used insecticides is a serious issue against whitefly and leafhopper on potato crop. Therefore, it is essential to study the economics and resurgence phenomena of whitefly and leafhoppers on potato crop while using the low, recommended and slightly higher doses of commonly recommended insecticides on potato crop under field conditions.

## MATERIALS AND METHODS

Field experiments were conducted to record the resurgence effect of commonly used insecticides like imidacloprid, thiamethoxam and oxydemeton-methyl against whitefly, *Bemisia tabaci* (Gennadius) and leafhoppers *Amrasca biguttula biguttula* Isida on early planted potato crop at ICAR-Central Potato Research Institute Campus, Modipuram, Meerut (U.P.) during two consecutive years 2018 and 2019. The experiment was laid out in a randomized block design with plot size of 3 m × 3 m. Potato cultivar, K. Pukhraj was planted in 4<sup>th</sup> week of September during the respective years with three replications. All the agronomical package and practices recommended for the region were followed in raising a good crop. Ten treatments *viz.* T1- Imidacloprid 17.8 SL @ 2ml/10 l, T2- Imidacloprid 17.8 SL @ 4ml/10 l, T3- Imidacloprid 17.8 SL @ 6ml/10 l, T4- Thiamethoxam 25% WG @ 3g/10 l, T5- Thiamethoxam 25% WG @ 5g/10 l, T6- Thiamethoxam 25% WG @ 7g/10 l, T7- Oxydemeton-Methyl 25 EC @ 2ml/l, T8- Oxydemeton-Methyl 25 EC @ 3ml/l, T9- Oxydemeton-Methyl 25 EC @ 4ml/l

and T-10 control (without spray) were given when crop was 30, 45, 55 and 65 days old at 10 days interval.

The observations on the mean population buildup of whitefly and leafhoppers was recorded on 05 randomly selected plants covering upper, middle and lower leaves of each plant at before and 24hrs, 36 hrs and 48 hrs after each spray. For spraying the crop, Knapsack sprayer was used and crop was sprayed in the evening to preserve active natural enemies during both the years. After each spray each plot was covered with insect proof net (40 mesh) to restrict the movement of whitefly and leafhoppers from one plot to another. Percent resurgence was calculated using Henderson and Tilton (1955) formula after modification by Jayraj and Ragupathy (1986),

$$\% \text{ resurgence} = (T_s / C_s \times C_p / T_f - 1) \times 100$$

(Where, TF= infestation in the treated plot during first count, TS= infestation in the treated plot during subsequent count, CF= infestation in the untreated control plot during first count, CS= infestation in the untreated control plot during subsequent count). The yield data was recorded from net plot after removing haulm in the last week of December during both the years. The percent over size, seed size and small size tubers were recorded at the time of harvest in each plot. Benefit-Cost analysis was expressed in terms of Benefit: Cost ratio by using the following formula

$$\text{Cost benefit: ratio} = \frac{\text{Net return (Rs. ha}^{-1}\text{)}}{\text{Cost of treatment (Rs. ha}^{-1}\text{)}}$$

The data was further subjected to statistical analysis. Similarly, the % increase in tuber yield over unsprayed crop was calculated as follows-

$$\% \text{ increase in tuber yield} = \frac{\text{Tuber yield in sprayed plot} - \text{Tuber yield in unsprayed plot}}{\text{Tuber yield in unsprayed plot}} \times 100$$

## RESULTS AND DISCUSSION

### Population buildup of whitefly, *B. tabaci* and leafhoppers *A. biguttula biguttula* on potato

A day before the spray the mean population of whitefly and leafhoppers was

almost uniform across the experimental plots on early potato crop (21.67-26.67/ 5plants) and (2.33-4.33/ 5plants), respectively during 2019. Whitefly population differ significantly 24, 36 and 48 hrs after first, second and third sprays except fourth one on potato during 2019. The lowest number pooled mean of whitefly per 05 plant was recorded in the Imidacloprid 17.8 SL @ 6ml/10l treated plot (0.11-10.4 whiteflies/ 05 plant) followed by (0.89-7.9 /5 plants) in sprayed plot of Thiamethoxam 25% WG @ 5g/10 l (Fig 1). Similarly, the lowest number pooled mean of leafhopper per 05 plant was recorded in the Thiamethoxam 25% WG @ 7g/10 l treated plot (0.22-1.0 leafhopper/ 05 plant) followed by (0.11-2.0 /5 plants) in sprayed plot of Imidacloprid 17.8 SL @ 6ml/10 (Fig 3). A perusal of mean data revealed that less incidence of whitefly and leafhopper was recorded during 2018 as compared to 2019 on early potato crop. However, it showed almost the same trend as per the incidence in treated plots of insecticides. A day before the spray the mean population of whitefly and leafhoppers was almost uniform across

the experimental plots on early potato crop (16.37-18.52/ 5plants) and (2.67-4.07/ 5plants), respectively during 2018. Whitefly population differ significantly 24, 36 and 48 hrs after first, second and third sprays except fourth one on potato during 2018. The lowest number pooled mean of whitefly per 05 plant was recorded in the Thiamethoxam 25% WG @ 7g/10 l treated plot (0.11-4.9 whiteflies/ 05 plant) followed by 0.11-7.13 /5 plants) in sprayed plot of Imidacloprid 17.8 SL @ 6ml/10l (Fig 2). Similarly, the lowest number pooled mean of leafhopper per 05 plant was recorded in the Thiamethoxam 25% WG @ 7g/10 l treated plot (0.11-0.56 leafhopper/ 05 plant) followed by 0.11-1.67 /5 plants) in sprayed plot of Imidacloprid 17.8 SL @ 6ml/10 (Fig 4).

No significant difference of whitefly population was noticed among sprayed treatments after the fourth spray in the 50 days old crop. However, a significant difference was recorded against the leafhopper population during 2018 and 2019. Bhatnagar *et al.*, 2013 reported that sharp decrease in temperature after mid-November decreased whitefly and

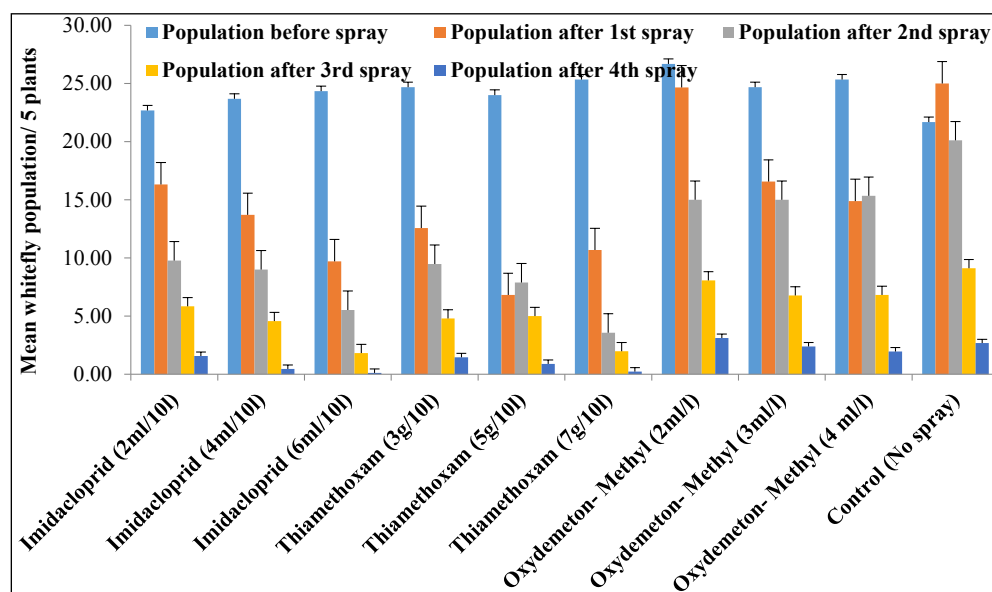


Fig. 1. Mean population buildup of whiteflies on potato after insecticide treatments during 2019

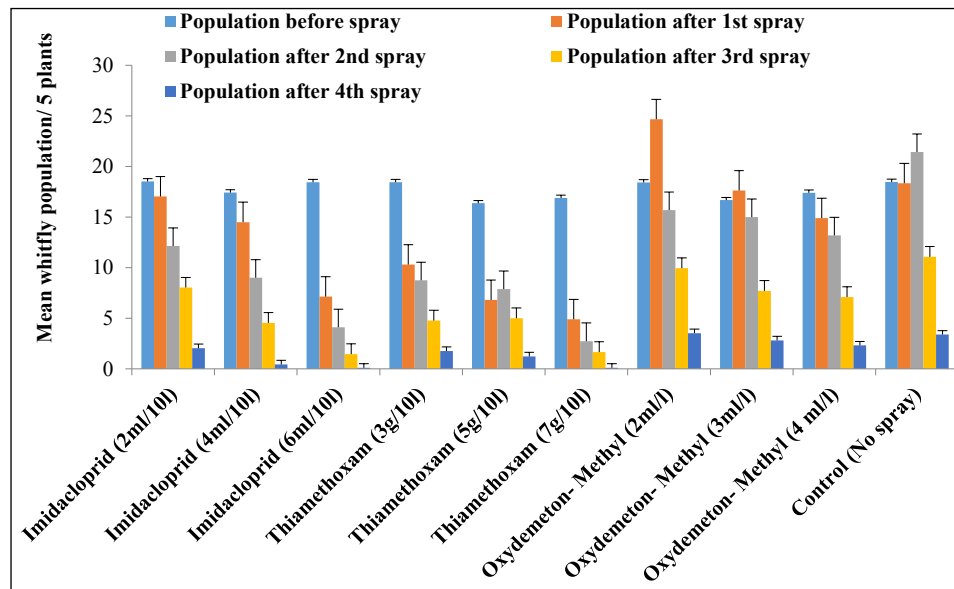


Fig.2. Mean population buildup of whiteflies on potato after insecticide treatments during 2018

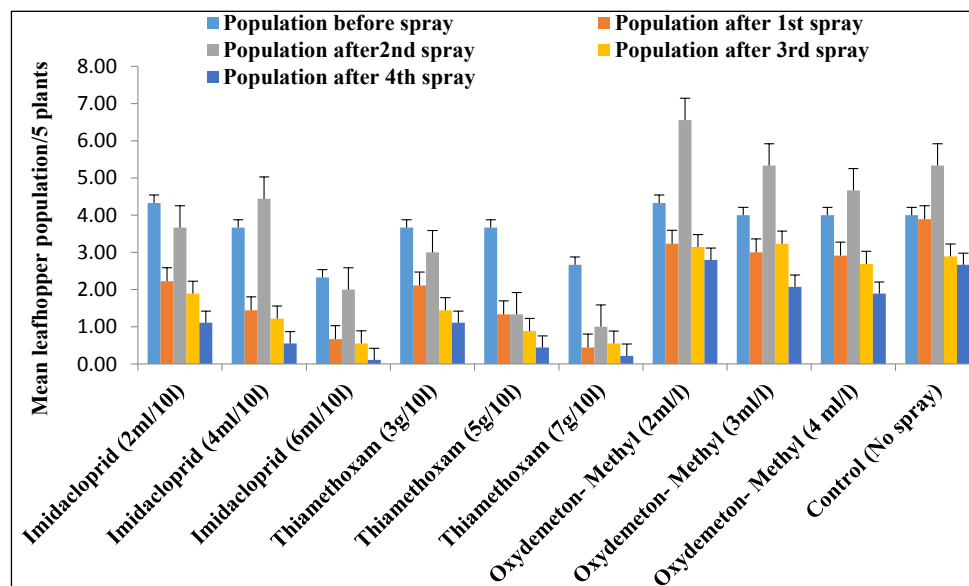


Fig.3. Mean population buildup of leafhoppers on potato after insecticide treatments during 2019

leafhoppers population drastically. Incidence of whitefly and leafhoppers population did not differ significantly in relation to plant protection treatments on potato crop after fourth spray. The earlier results indicate that, neonicotinoids provide excellent control of many sucking pests including leafhoppers and whitefly (Bhatnagar, 2007).

Our results are in agreement with Bhatnagar, 2007, who reported that neonicotinoids were effective against sap-feeding insect pests that are resistant to other classes of insecticides.

The population of *B. tabaci* and *A. biguttula biguttula* was active on potato crop

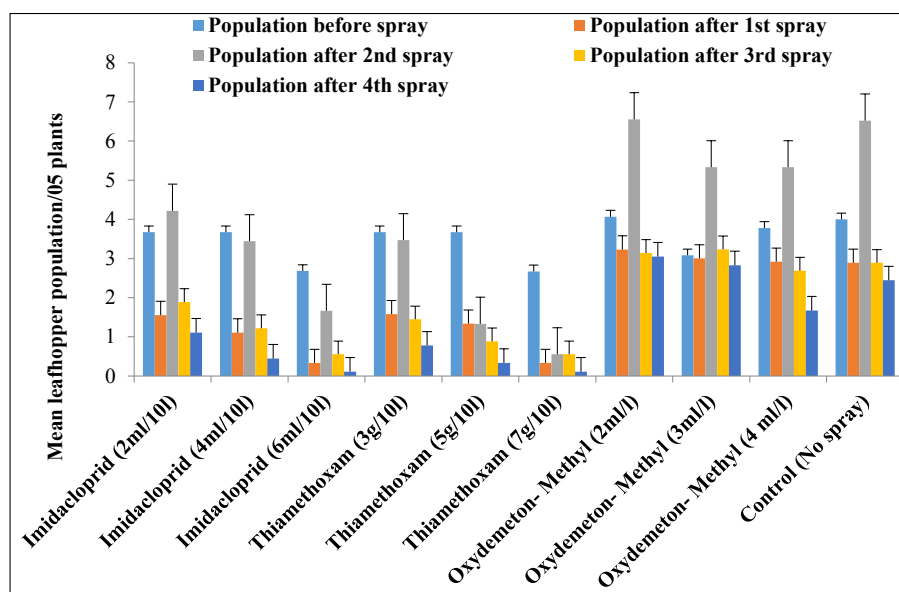


Fig.4. Mean population buildup of leafhoppers on potato after insecticide treatments during 2019

throughout the crop growth. The incidence of whitefly and leafhoppers population was resulted on early potato crop from residue population from natural host and weeds in the vicinity of the crop. However, the populations of whitefly and leafhoppers were indiscriminate on sprayed plots when crop was protected by four sprays of insecticides at low, higher and recommended doses against leafhoppers and whitefly. A perusal of whitefly incidence data revealed that whitefly has become a severe threat to potato crop by not only sucking the sap directly from the tender parts of potato plant and also transmitting important APCLV, resulting quick degeneration of potato seed (Bhatnagar, 2007 and Chandla *et al.*, 2001). Similarly, the incidence of leafhoppers has responsible for hopper burn especially in warmer region of the country.

#### Effect of commonly used insecticides on resurgence of whitefly in potato

Two years data of whitefly incidence revealed that moderate to high level of resurgence occurred at different doses of

Imidacloprid 17.8 SL, Thiamethoxam 25% WG and Oxydemeton- Methyl 25 EC from 1<sup>st</sup> spray to 4<sup>th</sup> spray of respective insecticide. Resurgence occurred as the calculated value of resurgence occurrence (%) was negative (Table-1 and 2). The percentage of resurgence was lowest in Thiamethoxam 25% WG @ 7g/10 l treated plot (-80.8%) after 1<sup>st</sup> spray followed by Thiamethoxam 25% WG @ 5g/10 l (-75.4%) and Imidacloprid 17.8 SL @ 6ml/10 (-65.4%), whereas highest in Oxydemeton- Methyl 25 EC @ 2ml/l (-19.8%) and Imidacloprid 17.8 SL @ 2ml/10(-37.6%) during 2019. Similarly, the per cent resurgence of whitefly was varied from (-20.8%-61.2%), (-43.9%-79.9%) and (+6.41%- +13.8%) for Imidacloprid 17.8 SL, Thiamethoxam 25% WG and Oxydemeton-Methyl 25 EC, respectively during 2018. All the doses of Oxydemeton -Methyl 25 EC showed resurgence of whitefly population after first spray. After the second, third and fourth sprays the magnitude of resurgence of whitefly was reduced than first spraying which was ranged from (-34.8% to 84.8%), (-28.2% to 82.4%) and (-21.4% to -96.3%),

Table 1. Effect of insecticides on resurgence of whitefly (*Bemisia tabaci*) in potato during 2019.

| Treatment                | Dose<br>ml/l | T <sub>F</sub> | C <sub>F</sub> | 1 <sup>st</sup> spray |                |              | 2 <sup>nd</sup> spray |                |              | 3 <sup>rd</sup> spray |                |              | 4 <sup>th</sup> spray |                |              |
|--------------------------|--------------|----------------|----------------|-----------------------|----------------|--------------|-----------------------|----------------|--------------|-----------------------|----------------|--------------|-----------------------|----------------|--------------|
|                          |              |                |                | T <sub>S</sub>        | C <sub>S</sub> | % resurgence | T <sub>S</sub>        | C <sub>S</sub> | % resurgence | T <sub>S</sub>        | C <sub>S</sub> | % resurgence | T <sub>S</sub>        | C <sub>S</sub> | % resurgence |
| Imidacloprid 17.8 SL     | 2/10         | 22.6           |                | 16.3                  |                | -37.6        | 9.77                  |                | -53.6        | 5.82                  |                | -38.9        | 1.56                  |                | -43.9        |
| Imidacloprid 17.8 SL     | 4/10         | 23.6           |                | 13.7                  |                | -49.9        | 9.00                  |                | -59.0        | 4.55                  |                | -54.3        | 0.44                  |                | -84.8        |
| Imidacloprid 17.8 SL     | 6/10         | 24.3           |                | 9.7                   |                | -65.4        | 5.52                  |                | -75.5        | 1.80                  |                | -82.4        | 0.11                  |                | -96.3        |
| Thiamethoxam 25% WG      | 3/10         | 24.6           |                | 12.5                  |                | -55.9        | 9.48                  |                | -58.6        | 4.78                  |                | -53.9        | 1.44                  |                | -52.4        |
| Thiamethoxam 25% WG      | 5/10         | 24.0           | 21.7           | 5.6                   | 25.0           | -75.4        | 7.88                  | 20.1           | -64.7        | 3.87                  | 9.11           | -61.7        | 0.89                  | 2.66           | -69.8        |
| Thiamethoxam 25% WG      | 7/10         | 25.3           |                | 10.6                  |                | -80.8        | 3.56                  |                | -84.8        | 1.96                  |                | -78.4        | 0.22                  |                | -92.8        |
| Oxydemeton- Methyl 25 EC | 2/1          | 26.6           |                | 24.6                  |                | -19.8        | 14.99                 |                | -39.4        | 8.06                  |                | -28.2        | 3.11                  |                | +94.9        |
| Oxydemeton- Methyl 25 EC | 3/1          | 24.6           |                | 16.5                  |                | -41.8        | 14.98                 |                | -43.3        | 6.76                  |                | -34.8        | 2.38                  |                | -21.4        |
| Oxydemeton- Methyl 25 EC | 4/1          | 25.3           |                | 14.9                  |                | -49.0        | 15.33                 |                | -34.8        | 6.80                  |                | -36.2        | 1.95                  |                | -26.7        |

T<sub>F</sub>= infestation in the treated plot during first count, T<sub>S</sub>= infestation in the treated plot during subsequent count, C<sub>F</sub>= infestation in the untreated control plot during first count, C<sub>S</sub>= infestation in the untreated control plot during subsequent count

Table 2. Effect of insecticides on resurgence of whitefly (*Bemisia tabaci*) in potato during 2018.

| Treatment                | Dose<br>ml/l | T <sub>F</sub> | C <sub>F</sub> | 1 <sup>st</sup> spray |                |              | 2 <sup>nd</sup> spray |                |              | 3 <sup>rd</sup> spray |                |              | 4 <sup>th</sup> spray |                |              |
|--------------------------|--------------|----------------|----------------|-----------------------|----------------|--------------|-----------------------|----------------|--------------|-----------------------|----------------|--------------|-----------------------|----------------|--------------|
|                          |              |                |                | T <sub>S</sub>        | C <sub>S</sub> | % resurgence | T <sub>S</sub>        | C <sub>S</sub> | % resurgence | T <sub>S</sub>        | C <sub>S</sub> | % resurgence | T <sub>S</sub>        | C <sub>S</sub> | % resurgence |
| Imidacloprid 17.8 SL     | 2/10         | 18.5           |                | 14.5                  |                | -20.8        | 12.14                 |                | -43.5        | 8.02                  |                | -27.7        | 2.04                  |                | -39.8        |
| Imidacloprid 17.8 SL     | 4/10         | 17.4           |                | 10.8                  |                | -37.4        | 9.00                  |                | -55.5        | 4.55                  |                | -56.4        | 0.44                  |                | -86.2        |
| Imidacloprid 17.8 SL     | 6/10         | 18.4           |                | 7.13                  |                | -61.2        | 4.10                  |                | -80.8        | 1.47                  |                | -86.7        | 0.11                  |                | -96.7        |
| Thiamethoxam 25% WG      | 3/10         | 18.4           |                | 10.3                  |                | -43.9        | 8.76                  |                | -59.1        | 4.78                  |                | -56.8        | 1.77                  |                | -47.6        |
| Thiamethoxam 25% WG      | 5/10         | 16.4           | 18.5           | 6.8                   | 18.3           | -58.3        | 7.89                  | 21.4           | -58.7        | 5.00                  | 11.0           | -49.4        | 1.22                  | 3.38           | -59.6        |
| Thiamethoxam 25% WG      | 7/10         | 16.9           |                | 4.9                   |                | -70.9        | 2.74                  |                | -86.0        | 1.67                  |                | -83.5        | 0.11                  |                | -96.5        |
| Oxydemeton- Methyl 25 EC | 2/1          | 18.4           |                | 24.6                  |                | +34.4        | 15.69                 |                | -26.7        | 9.94                  |                | -10.2        | 3.52                  |                | +4.14        |
| Oxydemeton- Methyl 25 EC | 3/1          | 16.7           |                | 17.6                  |                | +6.41        | 14.99                 |                | -23.0        | 7.70                  |                | -23.5        | 2.82                  |                | -8.22        |
| Oxydemeton- Methyl 25 EC | 4/1          | 17.4           |                | 14.9                  |                | +13.8        | 13.19                 |                | -34.7        | 7.10                  |                | -32.0        | 2.31                  |                | -27.5        |

T<sub>F</sub>= infestation in the treated plot during first count, T<sub>S</sub>= infestation in the treated plot during subsequent count, C<sub>F</sub>= infestation in the untreated control plot during first count, C<sub>S</sub>= infestation in the untreated control plot during subsequent count

respectively after second, third and four spraying of insecticides during 2019. Similar trend of resurgence was recorded during 2018 (Table-1 and 2). It was noticed that when Oxydemeton- Methyl 25 EC were sprayed on potato crop the chance of whitefly resurgence increased along with sub lethal doses of Imidacloprid 17.8 SL and Thiamethoxam 25% WG. Positive values indicate the resurgence of the whitefly population.

### Effect of commonly used insecticides on resurgence of leafhoppers in potato

The impact of commonly used insecticides on resurgence of leafhopper is presented in Table-3 and 4. The percentage of leafhopper resurgence values were also recorded negative in all the Imidacloprid 17.8 SL and Thiamethoxam 25% WG treated plots except Oxydemeton- Methyl 25 EC during both the year 2018 and 2019. The mean percentage of leafhopper resurgence after first spray was lowest in Thiamethoxam 25% WG @7 g/10l (-83.5%) followed by Imidacloprid 17.8 SL@6 ml/10l (-72.5%) whereas, highest in Oxydemeton- Methyl 25 EC@3 ml/l (-23.0%) and 2ml/l (-23.3%), respectively during 2019. It showed almost the same trend during 2018. All the doses of Oxydemeton -Methyl 25 EC showed resurgence of leafhoppers during the years 2018 and 2019. After the second spray the magnitude of leafhopper resurgence was varied from -37.2% to -69.0% (Imidacloprid 17.8 SL) and -39.2% to -72.0% (Thiamethoxam 25% WG) during the year 2019, while it was -30.0% to -61.8% (Imidacloprid 17.8 SL) and -42.5% to -87.2% (Thiamethoxam 25% WG) during the year 2018. After the third spray, the magnitude of leafhopper resurgence showed almost the same trend as after the second spray. The values of resurgence was varied from -61.6% to -92.9% (Imidacloprid 17.8 SL) and -54.9% to -87.7% (Thiamethoxam 25% WG) during the year 2019, while it was

Table 3. Effect of insecticides on resurgence of leafhoppers (*Anrasca biguttula biguttula*) in potato during 2019.

| Treatment                | Dose<br>ml/l | T <sub>F</sub> | C <sub>F</sub> | 1 <sup>st</sup> spray |                |              | 2 <sup>nd</sup> spray |                |              | 3 <sup>rd</sup> spray |                |              | 4 <sup>th</sup> spray |                |              |
|--------------------------|--------------|----------------|----------------|-----------------------|----------------|--------------|-----------------------|----------------|--------------|-----------------------|----------------|--------------|-----------------------|----------------|--------------|
|                          |              |                |                | T <sub>S</sub>        | C <sub>S</sub> | % resurgence | T <sub>S</sub>        | C <sub>S</sub> | % resurgence | T <sub>S</sub>        | C <sub>S</sub> | % resurgence | T <sub>S</sub>        | C <sub>S</sub> | % resurgence |
| Imidacloprid 17.8 SL     | 2/10         | 4.33           |                | 2.22                  |                | -47.3        | 3.66                  |                | -37.9        | 1.89                  |                | -39.8        | 1.11                  |                | -61.6        |
| Imidacloprid 17.8 SL     | 4/10         | 3.67           |                | 1.44                  |                | -59.7        | 3.00                  |                | -39.2        | 1.22                  |                | -54.4        | 0.55                  |                | -77.6        |
| Imidacloprid 17.8 SL     | 6/10         | 2.33           |                | 0.66                  |                | -72.5        | 1.00                  |                | -69.0        | 0.55                  |                | -67.5        | 0.11                  |                | -92.9        |
| Thiamethoxam 25% WG      | 3/10         | 3.67           |                | 2.11                  |                | -41.1        | 3.00                  |                | -39.2        | 1.44                  |                | -46.2        | 1.11                  |                | -54.9        |
| Thiamethoxam 25% WG      | 5/10         | 3.67           | 4.00           | 1.33                  | 3.89           | -63.3        | 1.33                  | 5.33           | -73.0        | 0.88                  | 2.89           | -67.1        | 0.44                  | 2.66           | -82.1        |
| Thiamethoxam 25% WG      | 7/10         | 2.67           |                | 0.44                  |                | -83.5        | 1.00                  |                | -72.0        | 0.55                  |                | -71.6        | 0.22                  |                | -87.7        |
| Oxydemeton- Methyl 25 EC | 2/1          | 4.33           |                | 3.23                  |                | -23.3        | 6.55                  |                | +13.0        | 3.14                  |                | -0.04        | 2.80                  |                | -3.15        |
| Oxydemeton- Methyl 25 EC | 3/1          | 4.00           |                | 3.00                  |                | -23.0        | 5.57                  |                | +14.5        | 3.23                  |                | +11.7        | 2.07                  |                | -22.2        |
| Oxydemeton- Methyl 25 EC | 4/1          | 4.00           |                | 2.91                  |                | -26.0        | 4.66                  |                | -12.6        | 2.69                  |                | -6.92        | 1.89                  |                | -28.9        |

T<sub>F</sub>= infestation in the treated plot during first count, T<sub>S</sub>= infestation in the treated plot during subsequent count, C<sub>F</sub>= infestation in the untreated control plot during first count, C<sub>S</sub>= infestation in the untreated control plot during subsequent count

Table 4. Effect of insecticides on resurgence of leafhoppers (*Amrasca biguttula biguttula*) in potato during 2018.

| Treatment                | Dose<br>ml/l | T <sub>F</sub> | C <sub>F</sub> | 1 <sup>st</sup> spray |                |              | 2 <sup>nd</sup> spray |                |              | 3 <sup>rd</sup> spray |                |              | 4 <sup>th</sup> spray |                |              |
|--------------------------|--------------|----------------|----------------|-----------------------|----------------|--------------|-----------------------|----------------|--------------|-----------------------|----------------|--------------|-----------------------|----------------|--------------|
|                          |              |                |                | T <sub>S</sub>        | C <sub>S</sub> | % resurgence | T <sub>S</sub>        | C <sub>S</sub> | % resurgence | T <sub>S</sub>        | C <sub>S</sub> | % resurgence | T <sub>S</sub>        | C <sub>S</sub> | % resurgence |
| Imidacloprid 17.8 SL     | 2/10         | 3.67           | 4.00           | 1.56                  | 4.22           | -41.8        | 4.22                  | 6.52           | -30.0        | 1.89                  | 2.89           | -29.4        | 1.11                  | 2.44           | -50.8        |
| Imidacloprid 17.8 SL     | 4/10         | 3.67           | 4.00           | 1.11                  | 3.44           | -58.1        | 3.44                  | 6.52           | -43.0        | 1.22                  | 2.89           | -54.4        | 0.44                  | 2.44           | -80.5        |
| Imidacloprid 17.8 SL     | 6/10         | 2.68           | 4.00           | 0.33                  | 1.67           | -82.9        | 1.67                  | 6.52           | -61.8        | 0.56                  | 2.89           | -71.1        | 0.11                  | 2.44           | -93.2        |
| Thiamethoxam 25% WG      | 3/10         | 3.67           | 4.00           | 1.58                  | 3.47           | -40.5        | 3.47                  | 6.52           | -42.5        | 1.45                  | 2.89           | -45.8        | 0.78                  | 2.44           | -65.4        |
| Thiamethoxam 25% WG      | 5/10         | 3.67           | 4.00           | 1.34                  | 2.89           | -49.9        | 1.33                  | 6.52           | -77.9        | 0.89                  | 2.89           | -66.7        | 0.33                  | 2.44           | -85.4        |
| Thiamethoxam 25% WG      | 7/10         | 2.67           | 4.00           | 0.33                  | 0.56           | -82.9        | 0.56                  | 6.52           | -87.2        | 0.55                  | 2.89           | -71.6        | 0.11                  | 2.44           | -93.2        |
| Oxydemeton- Methyl 25 EC | 2/1          | 4.07           | 3.00           | 3.23                  | 6.56           | +9.09        | 6.56                  | 5.33           | -1.39        | 3.14                  | 3.24           | +6.47        | 3.05                  | 2.83           | +22.5        |
| Oxydemeton- Methyl 25 EC | 3/1          | 3.08           | 3.00           | 3.00                  | 5.33           | +33.8        | 5.33                  | 5.33           | +5.45        | 3.24                  | 2.83           | +20.0        | 2.83                  | 2.83           | +49.6        |
| Oxydemeton- Methyl 25 EC | 4/1          | 3.78           | 2.92           | 2.92                  | 5.33           | +6.87        | 5.33                  | 5.33           | +14.2        | 2.69                  | 2.69           | -2.26        | 1.67                  | 1.67           | -28.1        |

T<sub>F</sub>= infestation in the treated plot during first count, T<sub>S</sub>= infestation in the treated plot during subsequent count, C<sub>F</sub>= infestation in the untreated control plot during first count, C<sub>S</sub>= infestation in the untreated control plot during subsequent count

-50.8% to -93.2% (Imidacloprid 17.8 SL) and -65.4% to -93.2% (Thiamethoxam 25% WG) during the year 2018 after fourth spray. It shows that no resurgence occurred in the recommended and slightly higher doses of Imidacloprid 17.8 SL and Thiamethoxam 25% WG. It is prominent from the experimental result depicted above that the Imidacloprid 17.8 SL and Thiamethoxam 25% WG induced no resurgence at recommended and slightly higher doses against whitefly and leafhoppers on potato crop but Oxydemeton-Methyl 25 EC was recorded high degree of resurgence against both the pests. However, Imidacloprid 17.8 SL @2ml/10l showed resurgence of whiteflies and leafhoppers in both the years. All other doses of Imidacloprid 17.8 SL and Thiamethoxam 25% WG showed moderate to maximum toxicity towards whitefly and leafhopper and prevented resurgence of both the insects. Although we are well acquainted that imidacloprid is a key insecticide, universally used for the management of sucking pests on potato but extensive and repeated use before imidacloprid for suppressing whitefly, aphids and leafhoppers has placed a heavy selection pressure on target insect, which may cause of reduced efficacy and resurgence of population. Besides that sub lethal exposure to imidacloprid and thiamethoxam may be stimulated whitefly and leafhopper population growth by increasing fecundity or shortening the development period. This phenomenon also might be attributed to diverse climate, cropping system and introduction of new potato varieties or may be wide spread use of pesticide related factors. The low efficacy of imidacloprid against adult whitefly and leafhopper was reported to be due to emergence of biotypes (Pirmoradi *et al.*, 2001). From our present findings it can be concluded that repeated use of imidacloprid and thiamethoxam should

be checked immediately and never to use its sub-lethal doses.

### Per cent different size of tubers, tuber yield and it's economics

Pooled per-cent mean numbers of different size tubers did not differ statistically among the different doses of insecticide treated plots (Table 5). Highest pooled mean tuber yield (21.81 t/ha) was recorded from Thiamethoxam 25% WG @ 7g/10l four sprays treated potato plot followed by sprayed plots of Imidacloprid 17.8 SL@6 ml/10l (20.60 t/ha) and Imidacloprid 17.8 SL@4 ml/10l (20.35 t/ha). The sub lethal doses of imidacloprid and thiamethoxam and all the doses of Oxydemeton- Methyl were recorded negative and no increase in potato yield over control. However, maximum (14.91 %) increase in tuber yield was recorded in thiamethoxam25% WG @ 7g/10l treated plot followed by Imidacloprid 17.8 SL@6 ml/10l (8.53%) (Table5). By working out cost benefit ratio it is evident that thiamethoxam25% WG @ 7g/10l treated plot ranked first indicating the maximum return of Rs. 2.99 per rupee invested followed by Imidacloprid 17.8 SL@6 ml/10l with Rs.2.09. Jaykar *et al.* (2019) also reported that K. Pukhraj, K. Khyati, K. Anand and K.Garima recorded the highest tuber yield under protected conditions. Further, Bhatnagar (2013) confirmed that soil application of insecticides and two to three sprays of insecticides were required for complete protection of potato crop against insect pests under field conditions.

### CONCLUSION

Three sprays of insecticides may be incorporated in the spray schedule against sucking pests especially whiteflies and leafhoppers for getting potential yield of potato. The use of pesticides from the emergence of potato crop to 55 days

Table 5. Effects of insecticides treatments on yield, % seed grade and C: B ratio of early potato (K. Pukhraj) crop (pooled data of 2018 & 2019)

| Insecticides treatments  | Dose ml/l | % Grade tubers |           |            | Mean tuber yield (t/ha) | Economics of treatments          |                                       |                                      |                                  |                      | Benefit: Cost Ratio (1/2) |
|--------------------------|-----------|----------------|-----------|------------|-------------------------|----------------------------------|---------------------------------------|--------------------------------------|----------------------------------|----------------------|---------------------------|
|                          |           | Over size      | Seed size | Small size |                         | % increase in yield over control | increase in yield over control (t/ha) | *Cost of increase yield potato (Rs.) | **Cost of plant protection (Rs.) | Net profit (Rs.) (2) |                           |
| Imidacloprid 17.8 SL     | 2/10      | 7.86           | 38.32     | 53.07      | 18.84                   | 0.73                             | 0.14                                  | 1120                                 | 3760                             | -2640                | -                         |
| Imidacloprid 17.8 SL     | 4/10      | 9.12           | 40.47     | 50.35      | 20.35                   | 7.21                             | 1.37                                  | 10960                                | 3960                             | 7000                 | 1:1.76                    |
| Imidacloprid 17.8 SL     | 6/10      | 5.50           | 43.50     | 51.00      | 20.60                   | 8.53                             | 1.62                                  | 12960                                | 4190                             | 8770                 | 1:2.09                    |
| Thiamethoxam 25% WG      | 3/10      | 5.87           | 40.87     | 53.25      | 18.63                   | 0.0                              | -0.35                                 | -                                    | 4760                             | -                    | -                         |
| Thiamethoxam 25% WG      | 5/10      | 6.44           | 47.86     | 45.69      | 20.33                   | 7.11                             | 1.35                                  | 10800                                | 4960                             | 5840                 | 1:1.17                    |
| Thiamethoxam 25% WG      | 7/10      | 8.58           | 42.85     | 48.56      | 21.81                   | 14.91                            | 2.83                                  | 22640                                | 5672                             | 16968                | 1:2.99                    |
| Oxydemeton- Methyl 25 EC | 2/1       | 6.17           | 37.78     | 56.03      | 17.86                   | 0.0                              | -1.12                                 | -                                    | 3242                             | -                    | -                         |
| Oxydemeton- Methyl 25 EC | 3/1       | 6.48           | 43.82     | 49.78      | 18.27                   | 0.0                              | -0.71                                 | -                                    | 3440                             | -                    | -                         |
| Oxydemeton- Methyl 25 EC | 4/1       | 7.91           | 42.62     | 49.45      | 18.49                   | 0.0                              | -0.49                                 | -                                    | 3682                             | -                    | -                         |
| Control (No spray)       | -         | 8.20           | 41.87     | 50.62      | 18.98                   | -                                | -                                     | -                                    | -                                | -                    | -                         |
| SEM <sub>±1</sub>        | -         | 1.91           | 4.16      | 3.46       | 0.75                    | -                                | -                                     | -                                    | -                                | -                    | -                         |
| CD (p=0.05)              | -         | NS             | NS        | NS         | 2.26                    | -                                | -                                     | -                                    | -                                | -                    | -                         |

Date of 1<sup>st</sup> spraying 27.10., 2<sup>nd</sup> 04.11., 3<sup>rd</sup> 14.11 and 4<sup>th</sup> 24.11. \* Cost of potato Rs. 8000/ t \*\* (Cost of plant protection- Labor+ spray product +Machine)

old effectively reduced the whitefly and leafhopper population and significantly increased tuber yield. It can be concluded that, imidacloprid and thiamethoxam are the preferred insecticides with appropriate doses having less toxicity to the mammals and can be used to control sucking insect pests in potato IPM programs.

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## CONFLICTS OF INTEREST:

The authors confirm that this manuscript has no conflicts of interest

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# BENEFICIAL EFFECTS OF BACTERIAL ENDOPHYTES ISOLATED FROM POTATO ROOTS AND TUBERS ON NUTRIENT SOLUBILIZATION

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**ABSTRACT:** The application of agrochemicals to improve nutrient uptake in plants has several negative effects on soil health. The use of plant growth-promoting rhizobacteria (PGPR) with nutrient solubilizing properties has become an attractive alternative to the synthetic chemicals. Endophytic bacteria have the potential to be utilized effectively in integrated nutrient management for crops. Being a vegetatively propagated crop, potato is continuously perpetuating a large number of microorganisms in its tuber as well as in its roots. Bacteria from potato tubers and roots were isolated and tested for their ability to solubilize Zn, P, and K and to produce siderophores on zinc, pikovskaya, aleksandrow, and chromo azurol S medium, respectively by serial dilution plate technique. A pot experiment was also conducted to study the effect of isolated endophytes on potato plant growth and yield. Among all, isolate PSB2 was found the best withstanding high pH and NaCl salt concentration. At seven days after inoculation (DAI) on respective media, it produced siderophore, IAA (9.79 g/ml), and solubilized phosphate (21.20 P g/ml). All six bacterial isolates showed a positive impact on growth and growth attributing characteristics in potato *cv. Kufri Jyoti*. Treatment T11 received recommended dose of nitrogen, phosphorus, and potassium (RD+NPK) + Zn in soil and a combination of endophytes isolates seed tuber treatment recorded maximum germination percent, plant height, fresh and dry biomass, and tuber weight which was significantly superior over un-inoculated control and at par with 100 % recommended dose of fertilizers (T1) suggesting possible saving in 25% of chemical fertilizers *viz.* phosphatic, potassium and zinc requirement in potato cultivation.

**KEYWORDS:** Potato, endophytes, zinc solubilizers, potassium solubilizers, siderophore

## INTRODUCTION

Endophytes live inside the plant in a non-pathogenic way and develop a mutualistic relationship (Montanez *et al.*, 2012). Endophytes produce secondary metabolites that protect plants against pathogens and pests. Some endophytes produce growth hormones like indole acetic acid (IAA) (Kumar *et al.*, 2021a), ethylene, and cytokinin. These microbes can be used in sustainable agriculture practices as this improves crop yield without harming the environment (Singh *et al.*, 2022). If endophytes are to be used in crop production systems, it will be necessary to manipulate bacterial populations in soils and plants. However, their role in

nutrient accumulation is not much explored. Hence, the study of endophytes and their compounds in crop production is needed in the present scenario of environmental pollution and climate change. Different parts of the potato are host to an abundance of endophytes. Both tubers and soil contain beneficial bacteria necessary for rhizosphere assembly and microbiota-mediated nutrient management. This can be converted into potato and ecosystem health microbiome management techniques.

Endophytes enhance the uptake of nitrogen for their host plant. In association with the host plant, this microorganism fixes atmospheric nitrogen in the presence

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of the nitrogenase enzyme (Montanez *et al.*, 2012). Soil application of phosphatic fertilizers makes available only a small amount of soluble phosphorus fraction for plant uptake. Endophytic microorganisms produce different acids and compounds such as phosphatases and phytases that hydrolyze organic phosphorus compounds that help the solubilization of fixed phosphorus (Kumar *et al.*, 2021b). Endophytic populations have been extracted from cactus, strawberries, sunflower, soybeans, and other legumes found to be mineral phosphate solubilizers (Dias *et al.*, 2009).

Potassium (K) deficits, on the other hand, are an issue because K depletes rapidly from soils due to crop absorption, runoff, leaching, and soil erosion (Sheng and Huang, 2002). Rock phosphate (P) and K materials are less expensive sources of P and K. Nevertheless, most of them are not readily available to plants since the minerals are released slowly, and their use as fertilizer frequently results in negligible yield improvements of existing crops (Zapata and Roy, 2004). Phosphorus solubilizing bacteria (PSB), potassium solubilizing bacteria (KSB), and zinc solubilizing bacteria (ZSB) have been utilized to enhance the solubilization of fixed P, K, and zinc (Zn) because they convert insoluble forms of nutrients into those that are soluble and available for plant growth (Nahas *et al.*, 1990). This conversion occurs via acidification, chelation, and exchange processes (Gerke, 1992) and generates powerful organic acids in the periplasm (Alexander, 1977), which are markers for routine isolation and selection of solubilizer (Illmer *et al.*, 1995). In sustainable agriculture, bio fertilizers have been employed as a source to boost plant nutritional content. Experiments were conducted to determine the efficacy of phosphate solubilizing bacteria *Bacillus megaterium* var. *phosphaticum* and

potassium solubilizing bacteria *Bacillus mucilaginosus* implanted in nutrient-deficient soil containing pepper and cucumber.

Utilizing fertilizers in conjunction with bio fertilizers enhanced the availability of P, K, and Zn in the soil and the uptake of nitrogen (N), P, K, and Zn by the shoot and root. *Bacillus mucilaginosus*, for example, has been shown to improve K availability in soils and mineral content in plants (Sheng *et al.*, 2002). An integrated application of rock P and K materials with co-inoculation of bacteria that solubilize them could provide a more rapid and consistent supply of P and K for optimal plant growth. These endophytes can be used as efficient biological plant growth promoters in sustainable crop production. Being a vegetatively propagated crop, the potato continuously perpetuates a large number of microorganisms in its tuber as well as in its roots. Hence, there is great scope for the identification of novel endophytes from potato tubers along with roots. To investigate their impact on potato plant growth parameters, we studied bacterial endophytes from the tubers and roots grown under field conditions.

## MATERIALS AND METHODS

Potato tubers and roots were collected from long term fertilizer experiment plot at ICAR-Central Potato Research Institute, Regional station, Meerut, Uttar Pradesh, India during Rabi season (year 2018). Freshly harvested potato roots were rinsed with tap water to remove any remaining soil. The surface of the roots and tubers were sanitized with 70% ethanol for 30 seconds and 2% sodium hypochlorite for five minutes, and then they were washed twice with sterilized distilled water (Elbeltagy *et al.*, 2000). Roots and tubers were chopped aseptically into 1–2 cm sections, macerated with 0.8% saline solution and quartz sand, and then

decimally diluted in 0.8% saline solution. Endophytic isolates with the following plant growth enhancing properties have been isolated: siderophore producer, which plays a significant role in plant iron nutrition and phytopathogen repulsion. Microorganisms that solubilize zinc, phosphate, and potassium mobilize soil nutrients and make them readily available to crop plants. The isolates were purified by subculture on their respective media, and a stock culture was kept at 4–5 °C for future research.

### **Characterization of isolated bacteria**

Standard protocols were used to determine the morphological properties, such as shapes, Gram reaction (Hucker and Conn, 1923), opacity, margin characteristics, and motility (Whittenbury, 1964) of all isolates.

### **Screening of bacterial isolates for their P, K, and Zn solubilization**

#### ***On agar plates***

Bacterial strains were evaluated for their ability to solubilize potassium, phosphorus, and zinc on modified Aleksandrov medium plates supplemented with mica powder (2 g/L), Pikovskaya Agar medium plates supplemented with calcium phosphate, and zinc solubilizing agar medium plates supplemented with zinc oxide, respectively. On the basis of the solubilization zone generated on medium plates after seven days of incubation at 28°C, the solubilization patterns of several strains were evaluated. The results were expressed as follows, according to Nguyen et al. (1992):  $SE = \text{Solubilization Diameter} / \text{Growth Diameter} \times 100$ .

### **Quantitative assessment of P, K, and Zn solubility**

#### ***In liquid culture***

100 ml Erlenmeyer flasks containing 20 ml of Pikovskaya (PKVK) Agar medium

were inoculated with an inoculum of bacterial isolates and incubated for seven days at 28 °C. The cultures were harvested by centrifuging at 5000 rpm for 20 minutes, and the phosphorous content in the culture supernatant was evaluated using the para molybdenum blue method (Olsen and Sommers, 1982). At 600 nm, a spectrophotometer was used to determine the color produced during P estimation (Naik *et al.*, 2008). Further, a quantitative examination of zinc solubilized in a liquid medium containing 5 mM zinc oxide was conducted. By inoculating 1 percent cultures of each endophyte in liquid medium and incubating at 30 °C, 150 rpm for seven days, the amount of zinc solubilized was determined by Atomic absorption spectrophotometer. As a control, uninoculated medium for each zinc salt was used. Mica was supplied as the sole potassium source to the liquid Aleksandrov medium to test the isolate's capacity to solubilize potassium. A quantitative determination of potassium solubilization was carried out in Erlenmeyer flasks containing 100 mL of Aleksandrov medium and inoculated in triplicate with KSB1 and KSB2. As a control, autoclaved, uninoculated media were used. The flasks were incubated in a BOD incubator at 28°C. With a flame photometer, the dissolved potassium in the culture's supernatant, which was made by filtering the culture with a Whatman filter number 42, was measured. All the tests were conducted in five replications.

### **Identification of bacteria using 16S rRNA sequences**

Morphological study of microorganisms is usually the initial step of identifying endophytes. However, molecular techniques are needed to confirm their existence. The following steps were followed for molecular identification of endophytes:

### Isolation of DNA:

Total genomic DNA was extracted as described by Chen and Kuo (1993). The cultures were grown at  $28 \pm 2$  °C for 48 h with vigorous shaking. Each culture (1.5 ml) was harvested by centrifugation for 3 min at 12,000 rpm. The cell pellet was re-suspended and lysed in 300 µl of lysis buffer (40 mM Tris-acetate pH 7.8, 20 mM sodium-acetate, 1 mM EDTA, 1% SDS, 20 µg RNase A) by vigorous pipetting and incubated for 30 min at 37 °C. To remove most proteins and cell debris, 100 µl of 5 M NaCl solution was added and mixed well, and then the viscous mixture was centrifuged at 12,000 rpm for 10 min at 4 °C. After transferring the clear supernatant into a new vial, an equal volume of chloroform was added, and the tube was gently inverted at least 50 times when a milky solution was completely formed. Following centrifugation at 12,000 rpm for 3 min, the extracted supernatant was transferred to another vial and the DNA was precipitated with 100 % ethanol, washed twice with 70 % ethanol, dried in speed-vacuum, and re-dissolved in 50 µl of TE buffer.

### PCR amplification of the 16S rRNA gene

Identification of the bacterial species was based on the sequencing of the 16S rRNA using the primers 27 F and 1492 R (Lane, 1991). Genomic DNA was extracted by the phenol/chloroform extraction method. The 16s rRNA gene was amplified using the universal primers 27F (5'-AGAGTTTGATCCTGGCTCAG -3') and 1492R (5'-GGTTACC TTG TTA CGA CTT-3') (Table 4). The reaction was carried out in a 50 microliter reaction mixture containing 1.5 mM MgCl<sub>2</sub>, 2.5 mM of each dNTP, 25 pmoles of forward and reverse primers, 50 mg of DNA template, and 3U Taq DNA polymerase with its reaction buffer.

### DNA extraction from gel (Gel elution)

The amplicons were gel eluted using the Min-elute gel elution kit following the manufacturer's instructions (Qiagen). Agarose 1.2 g was used to make the gel in 100 ml of 1 × TAE buffer. The solution of agarose and 1 × TAE buffer was heated up to 1 min to dissolve agarose. When cooled a bit, the gel was poured into the gel cast, the comb was fixed, and the gel was allowed to solidify for 20 min. Each sample prepared for running on gel had a volume of 40 µl mixed with 3 µl of loading dye. A 100 bp ladder was used to ascertain the size of the band. The gel was allowed to run for 40 min at 90 V. The bands on the gel were visualized and cut under a UV transilluminator and quantified at 260 nm using a spectrophotometer. The purified 16S rDNA amplicons were sequenced on an Applied Biosystems 3130 Genetic Analyzer (Applied Biosystems, CA, USA) (Sagar *et al.*, 2014).

### Analysis of 16S rRNA sequences

The sequencing of 16S rRNA was performed using both forward and reverse primers. The generated sequences were aligned using the BioEdit software, V. 7.2.5, and compared with NCBI databases and sequences showing [99 % similarity by the Nucleotide Basic Local Alignment Search Tool (BLAST) programme available at the National Center for Biotechnology Information (NCBI) BLAST server ([www.ncbi.nlm.nih.gov/BLAST](http://www.ncbi.nlm.nih.gov/BLAST)) (<http://www.ncbi.nlm.nih.gov/BLAST>) (<http://www.ncbi.nlm.nih.gov/BLAST>) (<http://www.ncbi.nlm.nih.gov/BLAST>) The nucleotide sequences determined in this study have been deposited in the Gene Bank database and accession numbers have been obtained.

### Effects of endophytes isolates on potato plants

Pot experiments were carried out at ICAR-Central Potato Research Institute,

Shimla, Himachal Pradesh, India during the year 2019 in a glass house in a completely randomized design (CRD) with three replicates. To determine the efficacy of the identified bacterial isolates as bio inoculants, sterilized soil and sand were combined in a 1:1 ratio and placed in plastic pots with a width of 12 cm. The potato tubers of cv. *Kufri Jyoti* were cut into pieces and left to dry for two days. Then, ten percent arabic gum was used to coat the pieces with selected isolates that had been grown in liquid culture medium for fifteen minutes. The pieces were then left to dry for fifteen minutes. Potato tubers were planted in pots below the soil's surface, faintly irrigated, and the remaining other activities were followed as per standard recommended agronomic package and practices of the region. After 30 and 60 days, potato plants were collected and measured for various growth parameters, including germination percentage, plant height (cm) at 30, 45, and 60 days after sowing (DAS), shoot length, fresh and dry weight for shoot, and tuber weight (g) at 90 DAS. Phosphorus, potassium, and zinc contents in shoots and tubers were determined according to the methods described by AOAC (2005). Treatment details of the experiment are presented in Table 1.

## 2.6 Statistical analysis

Analysis of variance (ANOVA) and LSD test were carried out for the acquired results according to Steel and Torrie (1980).

## RESULTS AND DISCUSSION

### Characterization of bacterial isolates

The colonies of the PSB1 isolates were regular, slightly raised, smooth and slimy, and opaque. The cells of all the isolates were gram-positive and short to long rods (Table 2). The colonies of the PSB2 isolates were irregular, convex, smooth and slimy, and opaque. The

**Table 1 - Treatment details to evaluate endophytic isolates efficiency in nutrient solubilization, plant growth and yield under in vivo conditions.**

| Treatment No | Nitrogen, phosphorous, potassium, Zinc<br>Chemical fertilizer (N, P <sub>2</sub> O <sub>5</sub> , K and Zn kg/ha) | B  | Biofertilizer (B)*                  |
|--------------|-------------------------------------------------------------------------------------------------------------------|----|-------------------------------------|
| T1           | 100%RDF                                                                                                           |    |                                     |
| T2           | 50%RDF                                                                                                            |    |                                     |
| T3           | 75%RDF                                                                                                            | B1 | PSB1                                |
| T4           | 75%RDF                                                                                                            | B2 | KSB1                                |
| T5           | 75%RDF                                                                                                            | B3 | ZSB1                                |
| T6           | 75%RDF                                                                                                            | B4 | PSB 2                               |
| T7           | 75%RDF                                                                                                            | B5 | KSB2                                |
| T8           | 75%RDF                                                                                                            | B6 | ZSB2                                |
| T9           | 75%RDF                                                                                                            | B7 | PSB1+KSB1+ ZSB 1                    |
| T10          | 75%RDF                                                                                                            | B8 | PSB2+KSB2+ ZSB 2                    |
| T11          | 75%RDF                                                                                                            | B9 | PSB1+KSB1+ ZSB 1+ PSB2+ KSB2+ ZSB 2 |

colonies of the KSB1 isolates were regular, slightly raised, smooth, and opaque. The colonies of the KSB2 isolates were irregular, convex, smooth, and opaque. The colonies of the ZSB1 isolates were regular, convex, smooth, and transparent. The colonies of the ZSB2 isolates were regular, undulated, convex, smooth, and opaque.

### Sequencing of the 16S rRNA gene and identification of native potential isolates

The partial 16S rRNA gene sequence of 1500 bp was determined, and the output data were saved in FASTA format as detailed in Supplementary Figure: S1. The generated sequences were analysed with BLAST (Basic Local Alignment Search Tool) to identify the cultures and to locate the closest match of the cultures; the result is provided in the Table 3.

### Isolation of endophytic bacteria and solubilization index

The present study was conducted to isolate and characterize P, K, and Zn

**Table 2 Morphological characteristics of the endophytic bacterial isolates from potato roots.**

| Bacterial isolate | Shape                 | Gram reaction | Margin characteristic | Elevation       | Opacity     |
|-------------------|-----------------------|---------------|-----------------------|-----------------|-------------|
| PSB1              | Regular, short rods   | +ve           | Entire                | Slightly raised | Opaque      |
| KSB1              | Regular, short rods   | +ve           | Entire                | Slightly raised | Opaque      |
| ZSB1              | Regular, short rods   | +ve           | Entire                | Convex          | Transparent |
| PSB2              | Irregular, short rods | +ve           | Undulated             | Convex          | Opaque      |
| KSB2              | Irregular, big rods   | +ve           | Entire                | Convex          | Opaque      |
| ZSB2              | Regular, short rods   | +ve           | Undulated             | Convex          | Opaque      |

**Table 3 Identification of phosphorus, potassium, zinc solubilizing isolates by 16S rRNA sequencing.**

| Isolate Code | Species                        | Accession number | Similarity |
|--------------|--------------------------------|------------------|------------|
| PSB1         | <i>Bacillus safensis</i>       | MT576065         | 100%       |
| KSB1         | <i>Pseudomonas</i> sp.         | MT576051         | 96%        |
| ZSB1         | <i>Bacillus cereus</i>         | MT576024         | 100%       |
| PSB2         | <i>Bacillus velezensis</i>     | MT575768         | 99%        |
| KSB2         | <i>Lelliottia amnigena</i>     | MT573876         | 98%        |
| ZSB2         | <i>Pseudomonas granadensis</i> | MT573221         | 99%        |

solubilizing strains of endophytic bacteria isolated from potato tubers and roots. A total of 25 rhizobacterial isolates were isolated from tubers and roots of potatoes. These isolates were purified and stored at a low temperature for further experimentation. Six out of these twenty-five rhizobacterial isolates showed strong solubilization of insoluble P, K, Zn compounds during the agar plate assay and were coded as PSB1, KSB1, ZSB1, PSB2, KSB2 and ZSB2. Results obtained from *in vitro* screening of selected isolates for their ability to solubilize potassium monohydrogen phosphate, mica, and zinc oxide (ZnO) revealed that these isolates solubilization index for P, K, and zinc ranged from 1.25-3.12, 1.38-2.70, and 1.22-3.00, respectively. P solubilizing isolates PSB1, PSB2, K solubilizing isolates KSB1, KSB2, Zinc solubilizing isolates ZSB1 and ZSB2 showed maximum P, K, Zn solubilization zone and were statistically at par with each other (Table 4, Figure 1). Similar result was found by Mumtaz *et al.* (2017) where zinc

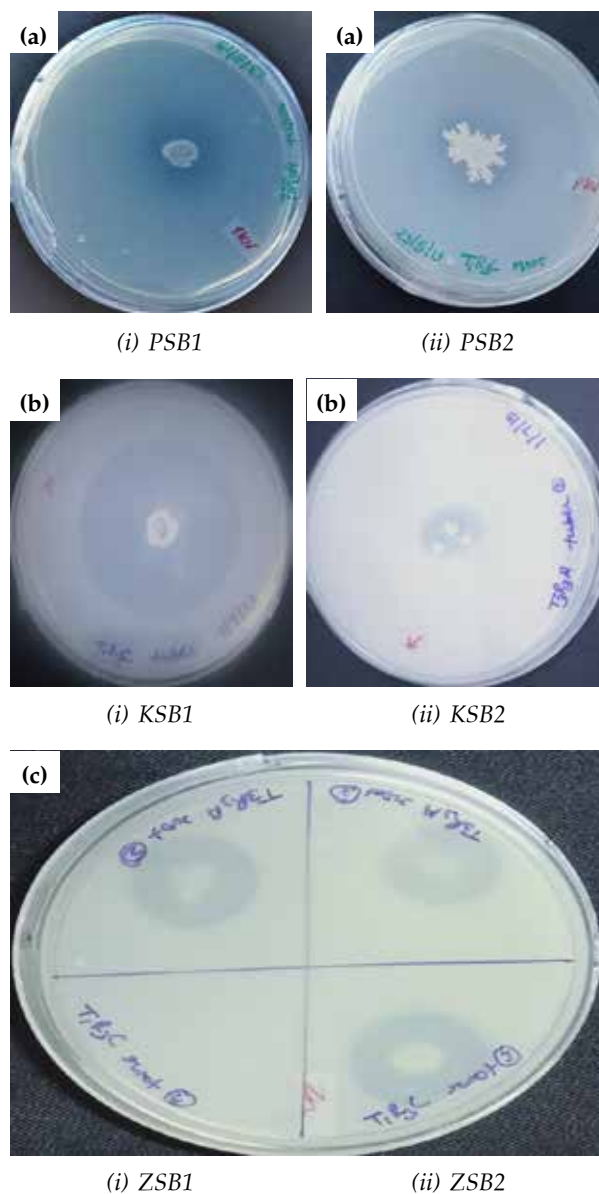


Figure 1(a) Phosphorus solubilizing bacteria, (b) Potassium solubilizing bacteria, (c) Zinc solubilizing bacteria

**Table 4 Phosphorus, potassium and zinc solubilization index (PSI, KSI, ZnSI) of endophytic isolates after 7 days of inoculation.**

| S. No. | Isolates No. | PSI                | KSI               | ZnSI              |
|--------|--------------|--------------------|-------------------|-------------------|
| 1      | PSB1         | 3.12 <sup>a*</sup> | 1.38 <sup>e</sup> | 1.22 <sup>f</sup> |
| 2      | KSB1         | 1.82 <sup>c</sup>  | 2.70 <sup>a</sup> | 1.95 <sup>c</sup> |
| 3      | ZSB1         | 1.39 <sup>e</sup>  | 1.62 <sup>d</sup> | 2.57 <sup>b</sup> |
| 4      | PSB2         | 2.90 <sup>b</sup>  | 2.08 <sup>b</sup> | 1.67 <sup>e</sup> |
| 5      | KSB2         | 1.67 <sup>d</sup>  | 2.62 <sup>a</sup> | 1.81 <sup>d</sup> |
| 2q6    | ZSB2         | 1.25 <sup>e</sup>  | 1.88 <sup>c</sup> | 3.00 <sup>a</sup> |

\*Means with the same letter are not significantly different at ( $p = 0.05$ ).

solubilizing bacteria produce 2.89-3.88 and phosphorus producing bacteria produce 2.33-4.03 solubilization index.

### Zinc, Phosphorus, Potassium Solubilization Assay

Estimation of P in the PKVK broth revealed that all the strains released P from tri calcium phosphate (TCP). At 7 days after inoculation (DAI), isolates PSB1 and PSB2 had the highest available phosphate levels of 82.86 mg/L and 76.08 mg/L, respectively, followed by KSB1 and KSB2 (Table 5). Estimation of K in the mica broth revealed that all the strains released K from mica. Isolates KSB1 and KSB2 recorded maximum available potassium of 64.19 mg/l and 55.27 mg/l, respectively, at 7 DAI, followed by ZSB1 and ZSB2. The

**Table 5 Test of phosphorus, potassium, and zinc solubilization ability of endophytic bacteria in broth was recorded after one weeks of incubation.**

| S. No. | Isolates No. | P mg/l<br>7 DAI     | K mg/l<br>7 DAI    | Zn mg/l<br>7 DAI   |
|--------|--------------|---------------------|--------------------|--------------------|
| 1      | PSB1         | 82.86 <sup>a*</sup> | 27.60 <sup>e</sup> | 17.76 <sup>e</sup> |
| 2      | KSB1         | 52.28 <sup>c</sup>  | 64.19 <sup>a</sup> | 20.75 <sup>d</sup> |
| 3      | ZSB1         | 13.44 <sup>e</sup>  | 49.18 <sup>c</sup> | 28.24 <sup>b</sup> |
| 4      | PSB2         | 76.08 <sup>b</sup>  | 30.36 <sup>e</sup> | 22.41 <sup>c</sup> |
| 5      | KSB2         | 29.70 <sup>d</sup>  | 55.27 <sup>b</sup> | 18.26 <sup>e</sup> |
| 6      | ZSB2         | 11.29 <sup>e</sup>  | 40.28 <sup>d</sup> | 33.62 <sup>a</sup> |

\*Means with the same letter are not significantly different at ( $p = 0.05$ ).

minimum potassium was utilized by PSB1 and PSB2. Estimation of Zn in the zinc oxide broth revealed that all the strains released Zn from ZnO. Isolates ZSB1 and ZSB2 recorded maximum available zinc of 28.24 mg/L and 33.62 mg/L, respectively, at 7 DAI, followed by PSB2 and KSB1 (Table 5). The present findings establish that phosphate, potassium, and zinc solubilization can improve the availability of phosphorus, potassium, and zinc in the crop rhizosphere. It has been found that a wide variety of soil bacteria and fungi can solubilize different types of precipitated P (Kucey *et al.*, 1983; Singh *et al.*, 2017; Lal *et al.*, 2022). These organisms are dominated by *Bacillus*, *Pseudomonas*, *Penicillium*, and *Aspergillus* spp. According to a study, the potassium-solubilizing bacteria *B. mucilaginosus* can dissolve rock K mineral powders like mica, illite, and orthoclases by making and releasing organic acids (Ullaman, 1996).

### pH Tolerance

PSB2 isolates have a wider pH (3-9) tolerance than other isolates, including PSB1, KSB1, ZSB1, PSB2, KSB2, and ZSB2. pH range (5-9) was observed for isolates KSB1 and KSB2 (Table 6). Bacterial growth was seen at pH 3 to 9 by isolates, but luxurious growth was observed between pH 5.0 and 7.0 for all the isolates. Gopalakrishnan et al. (2012) reported SRI-156 (*P. plecoglossicida*; NCBI Accession Number: JQ247008) as having the ability to tolerate pH between 5.0 and 13.0. In general, bacterial growth is higher in the pH range of 5.5-8.5.

### Salt Tolerance

All the tested isolates showed growth at salt concentrations of 1-2 percent. Growth of isolates PSB2 observed at higher salt concentration showing capacity to tolerate up to 5 per cent compared to other isolates

**Table 6 pH tolerance of endophytic isolates.**

| S. No. | Isolates No. | pH |   |   |   |   |   |   |   |
|--------|--------------|----|---|---|---|---|---|---|---|
|        |              | 2  | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1      | PSB1         | -  | - | + | + | + | + | + | - |
| 2      | KSB1         | -  | - | - | + | + | + | + | + |
| 3      | ZSB1         | -  | - | + | + | + | + | + | - |
| 4      | PSB2         | -  | + | + | + | + | + | + | + |
| 5      | KSB2         | -  | - | - | + | + | + | + | + |
| 6      | ZSB2         | -  | - | + | + | + | + | + | - |

(Table 7). For all isolates, 1 percent salt concentration resulted in the best growth. Gopalakrishnan *et al.* (2012) reported that *P. plecoglossicida* has the ability to tolerate salinity up to 6 per cent. Kuarabachew *et al.* (2007) observed that *P. fluoresces* can tolerate NaCl concentrations up to 3 percent in nutrient medium.

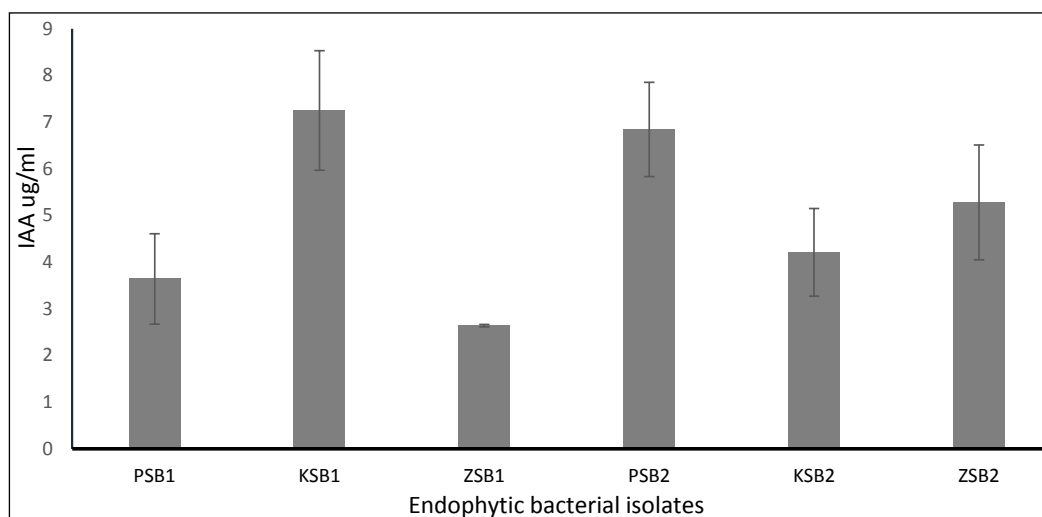
### Estimation of growth hormone IAA

All six examined isolates cultured in a culture medium contained tryptophan as a carbon source for IAA formation, as measured by the Salkowski reagent and spectrophotometer in the range of 2.64 to 7.25 ug/ml IAA (Figure 2). The higher concentration of IAA was obtained by the

**Table 7 Salinity tolerance of endophytic isolates.**

| S. No. | Isolates No. | Salinity % |   |   |   |   |
|--------|--------------|------------|---|---|---|---|
|        |              | 1          | 2 | 3 | 4 | 5 |
| 1      | PSB1         | +          | + | + | - | - |
| 2      | KSB1         | +          | + | - | - | - |
| 3      | ZSB1         | +          | + | + | + | - |
| 4      | PSB2         | +          | + | + | + | + |
| 5      | KSB2         | +          | + | + | - | - |
| 6      | ZSB2         | +          | + | - | - | - |

KSB1 strain at 7.25 ug/ml, followed by the PSB2 strain at 6.84 ug/ml. Estimation of IAA in the medium revealed that all the strains released IAA in tryptophan nutrient broth. Sakthivel and Karthikeyan (2012) carried out quantitative estimation of IAA

**Figure 2 Estimation of IAA from endophytic isolates.**

production by 30 bacterial isolates obtained from *Coleus forskohlii* rhizospheric soil of Perambalur and Salem districts in Tamil Nadu. IAA production by *Pseudomonas spp.* isolates ranges from 5.00–7.60 µg/ml, followed by *Azospirillum spp.* (3.10–6.80 µg/ml), *Azotobacter spp.* (3.00–6.30 µg/ml) and *Bacillus spp.* (2.40–5.80 µg/ml).

### Detection of Siderophore

Out of six endophytic bacteria, only four were able to produce a yellow color zone, which indicates the siderophore production capacity of isolates, wherein isolates PSB1, PSB2, KSB2 and ZSB1 positive siderophore (Table 8). On Chrom Azurol S agar, Dave and Dube (2000) also isolated six rhizobacterial *P. fluorescens*. Two of the six isolates produced the most siderophore. Sakthivel and Karthikeyan (2012) detected siderophore production and among the 30 isolates belonging to *Pseudomonas spp.*, *Azospirillum spp.*, *Bacillus spp.*, and *Azotobacter spp.*, produced siderophore. Siderophore chelates iron and other metals and contributes to disease suppression by conferring competitive advantages to biocontrol agents.

### Tuber inoculation efficacy of endophytic isolates on potato cv. Kufri Jyoti

A pot trial was carried out with a 100% recommended dose (full RD NP) of chemical fertilizer, i.e., (180 kg N/ha + 100 kg P<sub>2</sub>O<sub>5</sub>/

ha + 80 kg K<sub>2</sub>O/ha + 25 kg/ha ZnSO<sub>4</sub> and  $\frac{3}{4}$  RD (135 kg N/ha + 75 kg P<sub>2</sub>O<sub>5</sub>/ha + 45 kg K<sub>2</sub>O/ha + 18.75 kg ZnSO<sub>4</sub> /ha) as urea and SSP to study the effect of various endophytic bacterial isolates on Potato cv. Kufri Jyoti and also to demonstrate phosphorus, potassium, and zinc savings in potato by bio-inoculants (Table 1).

### Effect of endophytic isolates on potato plants germination and height

Data revealed that tuber inoculation of all the isolates significantly influenced germination per cent at 20 days after sowing (DAS). Among the different treatments of endophytic bacterial isolates, T11 and T9 recorded maximum germination per cent at 20 DAS, which was significantly superior to T1 (Figure 3). Endophytic bacteria induce the growth of plants as compared with uninoculated treatments. The results revealed that tuber inoculation of all the isolates significantly influenced plant height at 30, 45, and 90 DAS. Among the different strains of endophytic bacteria, combined application of isolates recorded maximum plant height at 30, 45, and 60 DAS, respectively, which was significantly superior over the un-inoculated control (Table 9).

Application of 75% fertilizer with endophytes significantly influenced plant height, i.e. T11 recorded 19.31, 46.25, and 67.22 cm, average plant height at 30, 45, and 90 DAS, respectively, which was at par with T10 (18.27, 39.36, and 58.05cm, respectively). This suggests combining the application of 75% of chemical fertilizers with bio fertilizers in potato cultivation enhances crop growth. A study conducted by Deivanai et al. (2014) on rice seedlings found that the inoculation of mangrove endophytic bacterial isolates has delayed the germination in both the pretreatments of rice seeds and increased the shoot length. A similar result was found

**Table 8** Estimation of siderophore production by endophytic bacterial isolates.

| S. No. | Isolates No. | Siderophore Detection |
|--------|--------------|-----------------------|
| 1      | PSB1         | +                     |
| 2      | KSB1         | -                     |
| 3      | ZSB1         | +                     |
| 4      | PSB2         | +                     |
| 5      | KSB2         | +                     |
| 6      | ZSB2         | -                     |

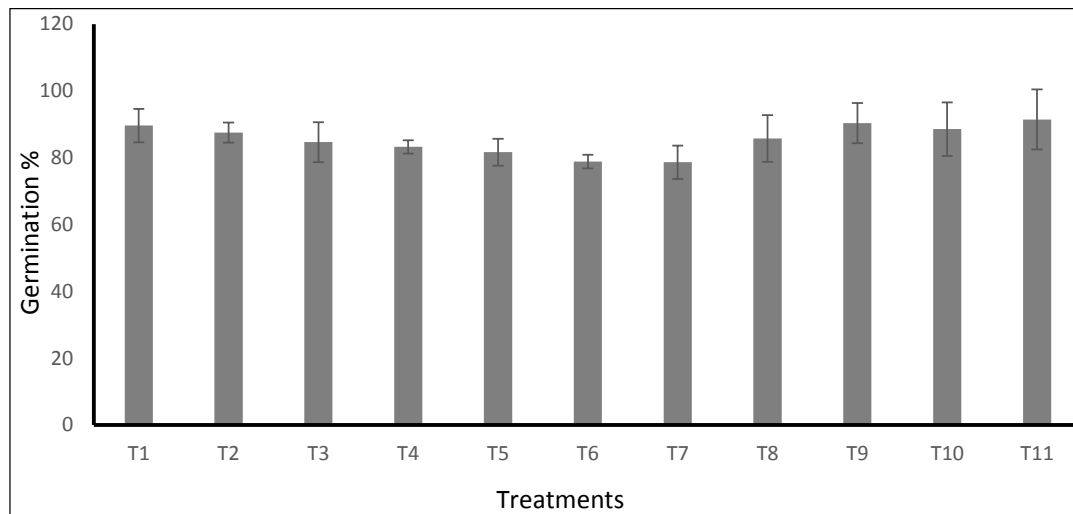


Figure 3 Inoculation efficiency of isolates in potato plant by germination per cent.

Table 9 Effect of endophytic bacterial isolates on plant height at 30,45 and 90 DAS.

| S. No. | Isolates No. | 30 DAS              | 45 DAS             | 90 DAS              |
|--------|--------------|---------------------|--------------------|---------------------|
| 1      | T1           | 18.39 <sup>b*</sup> | 40.23 <sup>b</sup> | 62.84 <sup>b</sup>  |
| 2      | T2           | 16.28 <sup>ef</sup> | 35.98 <sup>c</sup> | 49.28 <sup>e</sup>  |
| 3      | T3           | 15 <sup>g</sup>     | 32.21 <sup>d</sup> | 51.27 <sup>d</sup>  |
| 4      | T4           | 16.05 <sup>f</sup>  | 36.51 <sup>c</sup> | 44.58 <sup>f</sup>  |
| 5      | T5           | 17.25 <sup>cd</sup> | 32.85 <sup>d</sup> | 50.28 <sup>de</sup> |
| 6      | T6           | 16.5 <sup>e</sup>   | 35.55 <sup>c</sup> | 44.27 <sup>f</sup>  |
| 7      | T7           | 17.11 <sup>d</sup>  | 37.69 <sup>c</sup> | 41.22 <sup>g</sup>  |
| 8      | T8           | 16 <sup>f</sup>     | 33.74 <sup>d</sup> | 38.69 <sup>h</sup>  |
| 9      | T9           | 17.54 <sup>c</sup>  | 38.62 <sup>b</sup> | 49.26 <sup>e</sup>  |
| 10     | T10          | 18.27 <sup>b</sup>  | 39.36 <sup>b</sup> | 58.05 <sup>c</sup>  |
| 11     | T11          | 19.31 <sup>a</sup>  | 46.25 <sup>a</sup> | 67.22 <sup>a</sup>  |
|        | CV%          | 1.59                | 2.38               | 2.16                |
|        | SEm          | 0.073               | 0.81               | 1.18                |

\* Means with the same letter are not significantly different at ( $p = 0.05$ ).

by Mumtaz et al. (2017) where maize yield was enhanced with inoculation of maize seed with zinc solubilizing bacteria.

### P, K, Zinc contents in Shoots and tubers of inoculated and un-inoculated plants

A significant increase in P, K, and zinc content of shoots and tubers was

observed for the plants inoculated with all the endophytic isolates compared to the inoculated control. The highest amounts of P, K, and zinc were detected in shoots of treatment 11, which had 7.21, 45.29, and 0.041 mg/g of P, K, and Zn, respectively. The P, K, and Zn content of tubers was highest

Table 10 Effect of endophytic isolates on concentration of P, K Zn content of shoots.

| S. No. | Isolates No. | Phosphorus concentration in shoots (mg g <sup>-1</sup> ) | Potassium concentration in shoots (mg g <sup>-1</sup> ) | Zinc Concentration in shoots (mg g <sup>-1</sup> ) |
|--------|--------------|----------------------------------------------------------|---------------------------------------------------------|----------------------------------------------------|
| 1      | T1           | 5.35 <sup>d*</sup>                                       | 34.67 <sup>c</sup>                                      | 0.017 <sup>k</sup>                                 |
| 2      | T2           | 2.95 <sup>h</sup>                                        | 14.35 <sup>i</sup>                                      | 0.026 <sup>e</sup>                                 |
| 3      | T3           | 5.26 <sup>de</sup>                                       | 18.07 <sup>g</sup>                                      | 0.019 <sup>j</sup>                                 |
| 4      | T4           | 3.06 <sup>h</sup>                                        | 29.33 <sup>e</sup>                                      | 0.022 <sup>g</sup>                                 |
| 5      | T5           | 4.05 <sup>f</sup>                                        | 15.47 <sup>h</sup>                                      | 0.038 <sup>b</sup>                                 |
| 6      | T6           | 5.17 <sup>e</sup>                                        | 22.98 <sup>f</sup>                                      | 0.018 <sup>j</sup>                                 |
| 7      | T7           | 4.18 <sup>f</sup>                                        | 32.52 <sup>d</sup>                                      | 0.020 <sup>h</sup>                                 |
| 8      | T8           | 3.87 <sup>g</sup>                                        | 30.26 <sup>e</sup>                                      | 0.031 <sup>d</sup>                                 |
| 9      | T9           | 6.32 <sup>b</sup>                                        | 35.61 <sup>c</sup>                                      | 0.025 <sup>f</sup>                                 |
| 10     | T10          | 5.66 <sup>c</sup>                                        | 38.19 <sup>b</sup>                                      | 0.032 <sup>c</sup>                                 |
| 11     | T11          | 7.21 <sup>a</sup>                                        | 45.29 <sup>a</sup>                                      | 0.041 <sup>a</sup>                                 |
|        | CV %         | 1.95                                                     | 2.70                                                    | 4.19                                               |
|        | S.Em         | 0.009                                                    | 0.6                                                     | 2.47                                               |

\*Means with the same letter are not significantly different at ( $p = 0.05$ ).

for T11 (Table 10). Plants inoculated with strains PSB1 and PSB2 showed an increase in tubers and shoot P content as compared to un-inoculated controls. Plants inoculated with strains KSB1 and KSB2 showed an increase in tubers and shoot K content as compared to un-inoculated controls. Plants inoculated with strains ZSB1 and ZSB2 showed an increase in tuber and shoot Zn content as compared to un-inoculated controls (Table 11). These results indicate the efficacy of these PGPR strains in enhancing the bioavailability of P, K, and zinc and mobilising it toward tubers. Ghanbari et al (2022) demonstrated that the application of potassium, phosphorus, and iron-solubilizing bacteria considerably boosted the growth parameters of potato plants as well as their absorption of phosphorus, potassium, iron, and zinc. *Pseudomonas frederiksbergensis* to be the most potent bacterium in this investigation for most plant growth indices and nutrient absorption.

**Table 11 Effect of endophytic isolates on concentration of P, K, Zn content of tubers.**

| S. No. | Isolates No. | Phosphorus concentration in tubers (mg g <sup>-1</sup> ) | Potassium concentration in tubers (mg g <sup>-1</sup> ) | Zinc Concentration in tubers (mg g <sup>-1</sup> ) |
|--------|--------------|----------------------------------------------------------|---------------------------------------------------------|----------------------------------------------------|
| 1      | T1           | 3.15 <sup>ae</sup>                                       | 36.21 <sup>b</sup>                                      | 0.008 <sup>g</sup>                                 |
| 2      | T2           | 2.00 <sup>h</sup>                                        | 15.32 <sup>j</sup>                                      | 0.010 <sup>e</sup>                                 |
| 3      | T3           | 3.81 <sup>c</sup>                                        | 20.05 <sup>i</sup>                                      | 0.001 <sup>i</sup>                                 |
| 4      | T4           | 2.08 <sup>h</sup>                                        | 32.48 <sup>d</sup>                                      | 0.008 <sup>g</sup>                                 |
| 5      | T5           | 2.35 <sup>g</sup>                                        | 13.61 <sup>k</sup>                                      | 0.017 <sup>b</sup>                                 |
| 6      | T6           | 3.63 <sup>d</sup>                                        | 21.82 <sup>g</sup>                                      | 0.002 <sup>h</sup>                                 |
| 7      | T7           | 3.09 <sup>e</sup>                                        | 34.27 <sup>c</sup>                                      | 0.009 <sup>f</sup>                                 |
| 8      | T8           | 2.84 <sup>f</sup>                                        | 21.09 <sup>h</sup>                                      | 0.011 <sup>f</sup>                                 |
| 9      | T9           | 3.96 <sup>b</sup>                                        | 31.36 <sup>e</sup>                                      | 0.016 <sup>d</sup>                                 |
| 10     | T10          | 3.71 <sup>cd</sup>                                       | 28.29 <sup>f</sup>                                      | 0.028 <sup>c</sup>                                 |
| 11     | T11          | 4.18 <sup>a</sup>                                        | 45.08 <sup>a</sup>                                      | 0.035 <sup>a</sup>                                 |
|        | CV %         | 2.60                                                     | 1.78                                                    | 6.52                                               |
|        | S.Em         | 0.007                                                    | 0.23                                                    | 2.36                                               |

\*Means with the same letter are not significantly different at (p < 0.05).

### Inoculation efficacy of Isolates by fresh biomass, dry biomass, and tuber weight of Potato Plants at harvesting

Application of 75% NPK +Zn with endophytic isolates improves fresh biomass and tuber weight compared to uninoculated treatment (Table 12). The above results can be directly correlated with results of endophytic bacterial isolates from potato efficiency as well as in vitro studies of PGP traits, which may have a possible role in potato growth enhancement showing multiple PGP traits possession ultimately leading to enhanced plant growth. Growth hormone (IAA) and the availability of P, K, and Zn by inoculating endophytic isolates had a positive effect on germination rate, root growth, and shoot growth. Similarly, Khalil (2009) reported that single inoculation with bacteria, *P. putida*, *A. brasilense*, and *B. megaterium*, had a significant positive effect on shoot dry matter and also significantly increased root dry matter of potato plants. Kannapiran and Ramkumar (2011) reported that *A. chroococcum*, *A.*

**Table 12 Effect of endophytic bacterial isolates on fresh biomass, dry biomass and tuber weight of potato plants.**

| S. No. | Isolates No. | Fresh biomass (g)   | Dry biomass (g)     | Tuber weight (g)     |
|--------|--------------|---------------------|---------------------|----------------------|
| 1      | T1           | 34.31 <sup>ce</sup> | 24.15 <sup>c</sup>  | 154.39 <sup>c</sup>  |
| 2      | T2           | 26.31 <sup>g</sup>  | 18.36 <sup>h</sup>  | 125.41 <sup>g</sup>  |
| 3      | T3           | 34.27 <sup>c</sup>  | 25.08 <sup>b</sup>  | 139.36 <sup>f</sup>  |
| 4      | T4           | 32.09 <sup>e</sup>  | 21.58 <sup>de</sup> | 147.62 <sup>e</sup>  |
| 5      | T5           | 32.59 <sup>de</sup> | 20.19 <sup>f</sup>  | 152.78 <sup>d</sup>  |
| 6      | T6           | 33.25 <sup>cd</sup> | 24.16 <sup>c</sup>  | 150.20 <sup>de</sup> |
| 7      | T7           | 29.15 <sup>f</sup>  | 19.02 <sup>g</sup>  | 142.14 <sup>f</sup>  |
| 8      | T8           | 30.11 <sup>f</sup>  | 22.15 <sup>d</sup>  | 140.34 <sup>f</sup>  |
| 9      | T9           | 37.48 <sup>b</sup>  | 21.32 <sup>e</sup>  | 165.69 <sup>b</sup>  |
| 10     | T10          | 35.61 <sup>c</sup>  | 24.00 <sup>c</sup>  | 157.95 <sup>c</sup>  |
| 11     | T11          | 39.26 <sup>a</sup>  | 30.69 <sup>a</sup>  | 179.65 <sup>a</sup>  |
|        | CV %         | 2.28                | 1.84                | 6.52                 |
|        | S. Em        | 0.58                | 0.18                | 2.36                 |

\* Means with the same letter are not significantly different at (p < 0.05)

*beijerinckii*, *P. aeruginosa*, and *Bacillus spp.* enhanced shoot length, root length, and total dry mass as compared to control in black gram.

## CONCLUSION

Endophytic bacteria are plant-beneficial bacteria that exist within plants and can enhance plant growth under normal and adverse conditions. Being a vegetatively propagated crop, the potato continuously perpetuates a large number of microorganisms in its tuber as well as in its roots. We isolated P, K, Zn solubilizer and siderophore-producing bacteria from tubers and roots of potatoes. Endophytic bacterial isolates were capable of surviving high NaCl concentrations and a wide pH range. In vitro phosphate, potassium, zinc solubilization, siderophore production, and potato plant growth stimulation were observed by all isolates compared with the uninoculated control. Seed tuber bacterization with endophytic bacterial isolates in conjunction with 3/4 RD of NPK + Zn can substitute 1/4 of fertilizer requirement of potato.

## CONFLICTS OF INTEREST

The authors confirm that this manuscript has no conflicts of interest

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# ROLE OF SEED ON FUTURE POTATO PRODUCTION IN GUJARAT

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KEYWORDS Potato Seed, contract farming, table varieties potatoes, processing varieties, potatoes, seed rate

Gujarat holds first position in potato productivity having 30.64 tons/ha as compared to national average of 23.67 tons/ha in 2019-2020 (Panigrahy and Kalamkar, 2021). The Western region of India contributes 14.47 percent to national potato production, in which Gujarat accounts for 51.27 percent (GOI, 2017). Starting from infrastructural development (cold storage, logistics) to setting up many processing organizations, this state represents itself as a model in national spheres that pave a way towards potato business ecosystem. Despite all the rosy pictures and facts in favour of potato production of the state, cost of production has been increasing which is a matter of concern for many. It was observed that seed impacted maximum in cost of potato production (Pandey *et al.*, 2018) and Gujarat has the natural disadvantages being not fit to produce seeds due to its warmer climatic condition (Rana *et al.*, 2012). As a result, producers depend on other states for quality seed that escalates the cost of potato production. Seed is biological in origin and thus requires a specific temperature and humidity to be kept in cold storage. Many times, potatoes are used as seeds during subsequent year cultivation and even, some spurious seeds are also used by producers due to lack of

availability and dependency on the other states. Another concern in potato production is that yield was almost stagnant in spite of increase in area and production (Pandit and Chandran 2011; Rana and Anwar, 2018). Here, it becomes necessary to strengthen technological dimensions through better quality seed production in coming future for potato production. In different research, it has been observed that variable cost in potato production is significantly higher than fixed cost (Singh *et al.*, 2019; Sinha and Singh, 2019) and among the variables cost, seed cost shares maximum (Chaudhari *et al.*, 2017). It was also observed that in potato contract farming, seed cost had a vital share in overall input cost. It may be one of the reasons; many processing organizations are connecting with potato producers by supplying quality seeds at affordable rate with better accessibility. However, sometimes those seeds are shared and used by other noncontract producers. This situation brings legal impositions under plant varieties and farmers rights act 2001 as observed in Sabarkantha districts of Gujarat in 2019 where PepsiCo sued a case against four potato noncontract farmers for using its seeds without its knowledge and consent.

With this backdrop, seed has been found as a critical input in potato production

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and in state like Gujarat, its importance is highly significant among the producers due to unavailability and high cost of seeds. To understand about role of seed on potato business environment, three major objectives were tried to establish through this study;

1. Area, production and productivity of potato in Gujarat
2. Impact of potato seed on cost of cultivation in noncontract and contract farming
3. Analysis of potato seed rate in two different production system

The study was conducted in the state of Gujarat in 2019-2020. For accomplishing different objectives in this study, both primary, as well as secondary data were collected. The secondary data were compiled from the published reports and websites (Horticultural Statistics at a Glance, NHRDF, Office of the Director of Agriculture, Govt. of Gujarat, Gandhinagar etc). Primary level data were collected through pre-structured and tested schedules from selected potato farmers. Multistage random sampling technique was used for the selection of sample potato farmer households in Gujarat. Northern Gujarat and more specifically, Banaskantha, Arvali and Sabarkantha districts were selected here as these districts accounted 79 per cent of the total area under potato cultivation in Gujarat. After that a total of 10 talukas were selected from selected three districts, i.e. two talukas from Banaskantha district, five talukas from Sabarkantha district, and three talukas from Aravalli District. From ten selected tehsils, total thirty villages were identified according to their area covered under potato production after discussion with the taluka horticulture officer and elite farmers of the corresponding talukas.

As per the proportion of potato farmers in selected villages, a total of 1000 potato growers were selected randomly from selected villages to make a total sample of

1000 potato growers which comprised 180 farmers exclusively producing processing varieties of potato and 820 potato farmers exclusively producing table varieties. It was observed that processing varieties of potatoes are exclusively cultivated under contract system while table potatoes are cultivated in the regular mode by the farmers during survey agriculture year 2019-20.

The growth rate of APY (Area Production Statistics) of potatoes in Gujarat was worked out through the following formula

$$Y = ab^t e_t$$

Where Y = Dependent variable for which growth rate has been estimated

a = intercept

b = regression coefficient

t = time variable

e = error term

The linear form of the equation has been obtained after doing a logarithmic relationship among the variables

$$\log_e Y = \log_e a + t \log_e b$$

The compound growth rate (r) was computed by using the relationship

Where

$$R = [\text{Antilog } \log_e (b-1)] \times 100$$

The cost of cultivation of potatoes was calculated by using CACP (Commission for Agricultural Costs and Prices) method.

After that, all the input costs were categorized into variable cost and Fixed cost.

| Variable Cost                        | Fixed Cost                            |
|--------------------------------------|---------------------------------------|
| • Cost of potato seed                | • Cost of depreciation                |
| • Cost of fertilizer                 | • Cost of Interest on Working Capital |
| • Cost of Farmyard Manure            | • Cost of Rental Value                |
| • Cost of Irrigation Power           | • Cost of Overhead                    |
| • Cost of Weedicides                 | • Cost of Management                  |
| • Cost of Plant Protection Chemicals |                                       |
| • Cost of Hired Labour               |                                       |
| • Cost of Family Labour              |                                       |
| • Cost of Machine Labour             |                                       |
| • Cost of Mechanization              |                                       |

Potato production and subsequent consumption throughout India got momentum after the Liberalization, Privatization and Globalization (LPG) period. Its impact was also observed in all the states more particularly in Gujarat. Looking into the importance of production and area under potatoes after the LPG era, twenty-four years of data (from 1997-98 to 2019-20) were considered for the trend analysis purpose. It can be seen from Table 1 that during the period from 1997-98 to 2019-20, production of potato has increased by 436 per cent over the base year which was mainly due to 327 per cent increase in area under potato crop during the corresponding period. The productivity level of potato has increased by 25.5 per cent only. The highest rate of growth in potato production of 10.57 per cent was estimated during the period from 2000-01 to 2009-10. During the last decade also, production has increased at the rate of almost 9 per cent per annum mainly due to almost 7.5 per cent

**Table 1 Growth in Area, Production, and Productivity of Potato in Gujarat (1997-98 to 2019-20)**

| Particulars        |          | Area<br>(‘000 ha) | Production<br>(in ‘000 MT) | Yield<br>(Ton/ha) |
|--------------------|----------|-------------------|----------------------------|-------------------|
| TE 1997-98         |          | 29.37             | 692.07                     | 23.62             |
| TE 2002-03         |          | 33.63             | 766.03                     | 22.82             |
| TE 2012-13         |          | 75.76             | 2259.02                    | 29.75             |
| TE 2019-20         |          | 125.31            | 3709.82                    | 29.65             |
| Growth             |          |                   |                            |                   |
| 1996-97 to 1999-00 | CAGR (%) | 2.97              | -2.98                      | -5.92             |
|                    | Sig.     | 0.44              | 0.48                       | 0.15              |
| 2000-01 to 2009-10 | CAGR (%) | 8.54              | 10.57                      | 2.04              |
|                    | Sig.     | 0.00              | 0.00                       | 0.04              |
| 2010-11 to 2019-20 | CAGR (%) | 7.58              | 7.74                       | 0.16              |
|                    | Sig.     | 0.00              | 0.00                       | 0.68              |
| 1996-97 to 2019-20 | CAGR (%) | 7.45              | 8.97                       | 1.53              |
|                    | Sig.     | 0.00              | 0.00                       | 0.00              |

\*Note: Growth rate per cent per annum.

\*Source: Office of the Director of Agriculture, Govt. of Gujarat, Gandhinagar

per annum increase in area under potato during the said period. In the same period, yield was insignificant (sig value >0.5). Some of the steps like technological breakthrough in seed sector, infrastructural development, effective natural resource management and good agricultural practices may improve the yield of potato from the farmer's field in India.

The cost of cultivation is an important indicator of the inputs invested during production practices. It can be seen from comparative analysis of two production system (table 2) that cost of cultivation per

**Table 2 comparative cost of cultivation of potatoes in two production system**

| Input Particulars         | Non Contract Potato Farming (table varieties potatoes) |      | Contract Potato Farming (processing varieties potatoes) |      |
|---------------------------|--------------------------------------------------------|------|---------------------------------------------------------|------|
|                           | (n=820) Overall                                        |      | Overall (n=180)                                         |      |
|                           | Value (Rs)                                             | %    | Value                                                   | %    |
| Seed                      | 74691.3                                                | 53   | 96119.7                                                 | 62.6 |
| Fertilizer                | 23289.5                                                | 16.5 | 20216.7                                                 | 13.2 |
| FYM                       | 6253                                                   | 4.4  | 3295                                                    | 2.2  |
| Irrigation                | 1859.1                                                 | 1.3  | 1105                                                    | 0.7  |
| Weedicide                 | 1691.1                                                 | 1.2  | 1583                                                    | 1.0  |
| Plant Protection Chemical | 598.9                                                  | 0.4  | 647.7                                                   | 0.4  |
| Hired Labour              | 1633.4                                                 | 1.2  | 855.2                                                   | 0.6  |
| Family Labour             | 1637.1                                                 | 1.2  | 911.9                                                   | 0.6  |
| Machine Labour            | 212.6                                                  | 0.2  | 225.3                                                   | 0.2  |
| Mechanization             | 2190.9                                                 | 1.6  | 2325.5                                                  | 1.5  |
| Total variable cost       | 114056.9                                               | 81   | 127285.1                                                | 82.9 |
| Depreciation              | 109.5                                                  | 0.1  | 115.3                                                   | 0.1  |
| Interest                  | 1967.8                                                 | 1.4  | 7.6                                                     | 0.0  |
| Rental                    | 10629                                                  | 7.6  | 11607.8                                                 | 7.6  |
| Overhead                  | 1299.2                                                 | 0.9  | 822.7                                                   | 0.5  |
| Management                | 12808                                                  | 9.1  | 13646.5                                                 | 8.9  |
| Total Fixed Cost          | 26813.4                                                | 19   | 26199.9                                                 | 17.1 |
| Total Cost                | 140870.3                                               | 100  | 153485                                                  | 100  |

\*Source: Estimated using field survey data

hectare was estimated to be around Rs. 1, 40,870/- for table varieties of potatoes and Rs. 1,53,485/- for the processing one. It was observed that table varieties potato seeds shared 53 percent in overall cost of cultivation whereas processing varieties potato seed accounted 62.60 percent in its respective cost of cultivation. It was also inferred from the same table that total cost of cultivation per hectare for processing varieties of potatoes were 8.95 percent higher than the table varieties of potatoes. Similarly, cost of processing varieties seeds were 28.68 percent higher than cost of table varieties seeds in per hectare basis.

Seed is a major input that accounts significant share in the cost of cultivation of potatoes. The table variety potato growers had procured the seed tubers mostly from the Jalandhar market in Punjab state while few of

them had procured from some dealers in the local market while some of them have used their own. In the case of processing variety seed, seed was provided by the contracting firm. The seed rate estimated for processing varieties was found to be higher (35.35 qtls per hectare) than table varieties of potato (30.57 qtls/ha) (Table 3 and 4). The average market rate of seed used for table varieties of potatoes was estimated to be Rs. 1055/- per quintal while the same was estimated higher for processing varieties of potatoes which was provided by the contracting firm (Rs. 1372/- per quintal). For table varieties potatoes, the seed rate for the Pukhraj variety was lesser than Badshah variety due to the high moisture content in it.

Informal contract is very much flexible for both producers and processors. It helps to reduce the transaction cost of the processors

**Table 3 Details on Use of Potato Seed of Table Varieties**

| Source of Procurement                                                             | Average qtl seed used per ha | Price of seed per 50kg | % Bifurcation | No. of Potato Producers | Price of Potatoes for 20 kg |
|-----------------------------------------------------------------------------------|------------------------------|------------------------|---------------|-------------------------|-----------------------------|
| Jalandhar Market (By Producer)                                                    | 36.50                        | 1100-1200              | 55            | 451                     | 120-170                     |
| Jalandhar Market and Private Organization (By Cold Storage Manager)               | 31.14                        | 1100-1200              | 15            | 123                     | 120-170                     |
| Private Organizations through their dealers (Marino, Siddhibinayak, Kalindi, ITC) | 29.38                        | 1100-1200              | 10            | 82                      | 120-170                     |
| Own Seed                                                                          | 25.26                        | 900-950                | 20            | 164                     | 120-170                     |
| Total                                                                             | 30.57                        | 1055                   | 100           | 820                     | 149.78                      |

\*Source: Field survey data.

**Table 4 Details on Use of Potato Seed of Processed Varieties**

| Source of Procurement                                             | Average qtl seed used per ha | Price of seed per 50kg | % Bifurcation | Potato Producer | Price of Potatoes for 20Kg |
|-------------------------------------------------------------------|------------------------------|------------------------|---------------|-----------------|----------------------------|
| Through Formal Contract                                           | 35.20                        | 1300-1450              | 16.67         | 30              | 182-190                    |
| Through Informal Contract (Local Language only in the contract)   | 35.13                        | 1300-1450              | 18.52         | 33              | 180-190                    |
| Through Informal Contract (verbal contract)                       | 35.42                        | 1300-1450              | 47.69         | 85              | 200-240                    |
| Through Informal Contract (Price is written only in the contract) | 35.68                        | 1300-1450              | 17.13         | 32              | 180-190                    |
| Total                                                             | 35.35                        | 1372.00                | 100.00        | 180             | 186.80                     |

\*Source: Field survey data.

and generates ease of doing business for both the stakeholders. Wherever, seed price of processing potatoes were almost similar irrespective of contract or noncontract potato farming. It was observed during the field survey that the cost of seed for Santana variety was a little bit higher as demand for French fries has been increasing day by day. It has been observed from the above tables that the cost of seed of processing varieties was 30 percent higher than table varieties of potatoes. The sale price of the produce of these varieties per 20kg was also 24.71 percent higher than its counterpart. Though the seed cost of processing varieties was higher than the table varieties yet the better sale price of processing varieties added extra advantages in market. The cost of seed getting from the Jalandhar market was estimated to be higher which may be due to the number of traders pushing the seed at the Deesa market in the month of November. Due to poor availability, farmers/producers have been using the local market seed. Again, it was perceived that the seed of the Jalandhar market was comparatively better in quality as compared to other seeds, but it is costlier as well.

Growing seed cost is the matter of concern for potato producers in Gujarat that can be handled by increasing the accessibility of quality seed at producers door step. The coordination and cooperation of state agricultural universities, extension departments, and Krishi Vigyan Kendras (KVKs) assist the potato producers in getting the pertinent support and subsidies. State government may provide a platform of total stock and total supply in category wise by which potato producers can plan proper management of resources for utilization. Successful marketing channels (buyback arrangement of Banas Dairy & Hyfun Company) may be replicated for other

producers and processors for reaping its benefit from potato farming in Gujarat.

## CONFLICTS OF INTEREST

The authors confirm that this manuscript has no conflicts of interest

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## GREENHOUSE GAS EMISSIONS FROM POTATO CROP

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Human-produced gases including carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O) contribute to the natural greenhouse effect. The Intergovernmental Panel on Climate Change (IPCC) has concluded that immediate action is required to mitigate the severe risk of human-induced climate change posed by these gases. According to the IPCC (2001) report, agriculture contributes approximately 4% of global carbon emissions from energy use. Agriculture produces emissions through a variety of processes, including enteric fermentation and animal waste disposal and fermentation, anaerobic process during rice cultivation, nitrification and de-nitrification linked to fertilisation, as well as land clearing, the burning of biomass, fuel wood, and agricultural waste.

The Ministry of Environment and Forests (MoEF, 2010) estimated that approximately 13 percent of Indian agricultural GHG emissions are attributable to N<sub>2</sub>O. In addition to being a greenhouse gas, N<sub>2</sub>O also contributes to the depletion of ozone (O<sub>3</sub>) (Knowles, 1982). Nitrogen is often the most important and limiting nutrient for agricultural production. The world's nitrogen

fertiliser consumption increased from 12 Tg in 1960 to 113 Tg in 2010. (Fagodiya *et al.*, 2017). In addition, the nitrogen cycle includes nitrification, assimilation, ammonification, and denitrification (Kumar and Sharma, 2017b). N<sub>2</sub>O production in agricultural settings is predominantly the outcome of microbial denitrification and nitrification processes. In humid and subhumid regions, denitrification is the primary contributor to N<sub>2</sub>O production from agricultural soils (Li *et al.*, 2016). There are both direct and indirect impacts of reactive nitrogen (Nr) on soil N<sub>2</sub>O emissions. Due to their prolonged air lifetime (approximately 116 years), maximum capacity for global warming (310 times that of CO<sub>2</sub>), and significant potential for global climate change (290 on a 100-year basis), N<sub>2</sub>O emissions are of great concern (Fagodiya *et al.*, 2020a). Direct and indirect N<sub>2</sub>O emissions might come from the addition of nitrogen fertiliser to the soil. Direct emissions are the additional application of nitrogen fertilisers to the same soil (Holka and Bienkowski, 2020). Indirect N<sub>2</sub>O emissions are those that originate from non-soil sources and should not be regulated, such as N<sub>2</sub>O produced by water and NO<sub>3</sub> leaching into the soil (IPCC,

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2006). Agriculture and horticulture are responsible for around 8% of CO<sub>2</sub> emissions. N<sub>2</sub>O and CH<sub>4</sub> are major greenhouse gases that contribute 57% and 35%, respectively, to global warming (FAS, 2014). N<sub>2</sub>O is an extremely potent greenhouse gas that contributes directly to global warming. Due to its long atmospheric residence time (114 years), global climate change potential (290 times that of CO<sub>2</sub>), and global warming potential, N<sub>2</sub>O emissions over a 100-year period were more sensitive than those of other greenhouse gases (265 times higher than CO<sub>2</sub>). After CO<sub>2</sub> and CH<sub>4</sub>, these gases are the third most abundant greenhouse gas. In 2014, about 18.09 percent of all greenhouse gases and 73.29 percent of all N<sub>2</sub>O were emitted by the agriculture industry in India. A growing population needs the use of nitrogen fertiliser to meet the demand for food production, resulting in an increase in agricultural N<sub>2</sub>O emissions.

The potato is the fourth most important food crop in the world, after wheat, rice, and corn, due to its high yield potential and nutritional value (Kumar *et al.*, 2020). In India, the potato is not primarily a rural staple food, but rather a cash crop that provides farmers with substantial money. In order to attain the tuber yield and size distribution required by the potato processing industry, the potato crop often receives 200 kg N ha<sup>-1</sup> or more of nitrogen fertiliser (Zebarth *et al.*, 2012). Concerns have been raised about the potential for increased N<sub>2</sub>O emissions resulting from these high N inputs. Commonly, soil NO<sub>3</sub><sup>-</sup> availability, soil aeration, and soil carbon availability are cited as significant factors governing N<sub>2</sub>O emissions and denitrification (Gillam *et al.*, 2008).

Fertilizer management, formulation, and placement technologies provide the opportunity to influence the magnitude of

N<sub>2</sub>O emissions from fertiliser N sources by regulating the duration and extent of NO<sub>3</sub><sup>-</sup> accumulation in soil (IPCC, 2001).

Taking this into consideration the present experiment was conducted in ICAR-CPRI, regional station, Modipuram. We studied the effect of nitrogen rates (180 and 270 kg h<sup>-1</sup>), method of application of nitrogen fertilizers (Broadcast and band placement) and sources of nitrogenous fertilizer (Urea and ammonium sulphate) on N<sub>2</sub>O emission from soil in Potato (var. K. Pukhraj). Samples for GHG analysis was collected from potato field, each treatment replicate by placing one box per replicate 1 and 2 day prior to sowing; and on consecutive 15 days after fertilizer application after that once in a week (Figure 1). Estimation of total N<sub>2</sub>O emissions during the crop season was done by successive linear interpolation of average



Figure-1-Collection of GHGs samples from field using the closed-chamber method.

emission on the sampling days assuming that emission followed a linear trend during the periods when no sample was taken (Pathak et al. 2002) (Figure-1). Nitrous oxide concentration in the gas samples was estimated by Gas Chromatograph. Cumulative  $N_2O$  losses was calculated stepwise for each individual soil-collar area assuming a constant flux rate beginning with the date of each gas sampling until the next gas sampling. The cumulative fluxes at a site was expressed as arithmetic means. Potato yields will be determined from the total plot area. Duncan's Multiple Range Test was carried out to test whether the differences between means statistically significant.

$N_2O$  flux from the treatments showed more or less similar temporal trends with appearance of a peak of  $N_2O$  emission one and a half weeks after urea and ammonium sulphate application, however, the magnitude of flux differed. The cumulative emission of  $N_2O$ -N from potato treatments varied from 0.34 to 2.04 kg ha<sup>-1</sup>(Table 1). Urea and ammonium sulphate additions potentially affect  $N_2O$  emissions because they have different nitrification rates and have opposite effects on soil pH. Our results indicate that application of urea led to significant increase

in  $N_2O$  emissions over the application of ammonium sulphate. The emission was significantly higher under band placed urea as compared to broadcasting of urea. This may suggest that deep placement of nitrogen fertilizers in light sandy soils might not lead to the mitigation of GHG emissions from the soil. The deep N-fertilizer placement method, however, will be required for better plant nutrition, rather than the possibility of reducing GHG emissions from soil (Sosulski, 2020). However, for ammonium sulphate,  $N_2O$  emission from band placed and broadcasting had variable emission. The emission was higher under 270 kg ha<sup>-1</sup> application of nitrogen and urea as a source of fertilizer treatments. Overall,  $N_2O$  emission was significantly highest for 270 kg ha<sup>-1</sup> band placed urea fertilizer. Significant positive correlation was found between doses of fertilizer and  $N_2O$  emission. As expected, application of N fertilizer significantly increased total tuber yield and the yield was highest under 270 kg ha<sup>-1</sup> broadcasted urea (24.6-ton ha<sup>-1</sup>), however, higher dose of fertilizers leads to higher emissions. Sun *et al.* (2016) also found that the critical factors for  $N_2O$  emission were N fertilizer application rate. Kumar *et al.* (2021) conducted similar study for maize-wheat cropping system and

Table 1. Variations in tuber number, yield and  $N_2O$  emission under different treatments in potato.

| Treatments                                      | Total tuber number ('000)/ha | Fresh weight of tuber(ton/ha) | $N_2O$ Flux g/ha     |
|-------------------------------------------------|------------------------------|-------------------------------|----------------------|
| T1 (Control)                                    | 281.7 <sup>c</sup>           | 9.97 <sup>b</sup>             | 339.29 <sup>h</sup>  |
| T2 (180 kg N/ha urea broadcasting)              | 412.2 <sup>ab</sup>          | 21.99 <sup>a</sup>            | 1219.27 <sup>e</sup> |
| T3 (180 kg N/ha ammonium sulphate broadcasting) | 392.5 <sup>ab</sup>          | 23.75 <sup>a</sup>            | 1045.74 <sup>f</sup> |
| T4 (180 kg N/ha urea band placed)               | 362.2 <sup>abc</sup>         | 22.94 <sup>a</sup>            | 1439.38 <sup>c</sup> |
| T5 (180 kg N/ha ammonium sulphate band placed)  | 407.8 <sup>ab</sup>          | 24.48 <sup>a</sup>            | 772.38 <sup>g</sup>  |
| T6 (270 kg N/ha urea broadcasting)              | 342.8 <sup>bc</sup>          | 24.62 <sup>a</sup>            | 1324.80 <sup>d</sup> |
| T7 (270 kg N/ha ammonium sulphate broadcasting) | 402.87 <sup>ab</sup>         | 24.10 <sup>a</sup>            | 1250.08 <sup>e</sup> |
| T8 (270 kg N/ha urea band placed)               | 352.5 <sup>abc</sup>         | 22.19 <sup>a</sup>            | 2041.91 <sup>a</sup> |
| T9 (270 kg N/ha ammonium sulphate band placed)  | 430.0 <sup>a</sup>           | 22.62 <sup>a</sup>            | 1833.07 <sup>b</sup> |

<sup>a</sup>Means with the same letter are not significantly different at (p=0.05).

found that highest N<sub>2</sub>O efflux (0.368 kg per ton) was observed at higher dose of nitrogen application (240 kg N per hectare) under wheat crop. He also concluded that direct emission of N<sub>2</sub>O was totally dependent on N fertilizers application rate. It was also found that alkaline-forming fertilizers, such as urea tend to produce more N<sub>2</sub>O when they are locally concentrated, e.g. in bands, rather than dispersed evenly in the soil. It can be concluded that the emission of N<sub>2</sub>O was significantly higher under band placed urea applied at rate of 270 kg ha<sup>-1</sup>. Therefore, fertilizer N management in potato is very much important in reducing the risk of N<sub>2</sub>O emissions from soil.

## CONFLICTS OF INTEREST

The authors confirm that this manuscript has no conflicts of interest

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# PHYSIOLOGICAL, GROWTH AND YIELD RESPONSE OF POTATO (*Solanum Tuberosum* L.) TO HEAT STRESS

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**ABSTRACT:** Climate change adversely affects crop production as the associated rising temperatures damage its physiology and overall yield. Heat stress affects potato at various stages of growth, but sprout development and tuber initiation are the most sensitive to high temperatures. It also affects the photosynthesis (especially PII) activity, thereby limiting the production and partitioning of assimilates to the sink (tuber). The night temperature is more critical for potato tuber initiation and development. Tuber induction is best at 15°C, initiation at 22°C, and setting at 15°C. Yields are expected to decline by 18–32% in the 2050s due to the effects of global warming on potato cultivation. In addition, heat stress impacts quality resulting in physiological disorders. It also impairs the nutritive quality by boosting glycoalkoid levels in tubers, making the tuber bitter to consume. Therefore, strategies must be developed to combat the impact of heat stress. Priority strategic areas include the production of heat-tolerant potato genotypes by genetic engineering techniques such as screening, selection, and breeding as well as exogenous applications of osmoprotectants and agronomic methods.

**KEYWORDS:** Heat stress; Potato; Growth; Physiology; Yield; Quality

## 1. INTRODUCTION

Potato (*Solanum tuberosum* L.) is the world's most important vegetable crop, capable of ensuring food security in the face of mounting demand. With 381 million tons produced annually, it is the world's fourth most important food crop, after wheat (729 million tons), rice (741 million tons), and corn (741 million tons) (1037 million tons) (Ruan et al., 2021); but it ranked first among the non-cereal crops. Potato is a nutritious vegetable that is regarded as one of the most beneficial crops for reducing hunger, malnutrition, and poverty around the world because of its great productivity, as can be seen by its remarkably high harvesting index of over 75% (Wijesinha-Bettoni & Mouillé, 2019). Hence, potato has the potential to significantly contribute to human nutrition as an addition to other staple crops like rice and wheat (Campos & Ortiz, 2020).

For food security, understanding the effects of climate change on potato yield is

critical. Extreme heat and drought brought on by global climate change pose a significant threat to long-term crop production by reducing plant performance and output. Such a negative influence on agricultural productivity is projected to worsen in the future (Chourasia et al., 2021) due to increasing greenhouse gas emissions, which will lead to increased evapotranspiration and drought severity (Dahal et al., 2019).

When heat stress and moisture stress are combined, the result is massive losses in the agricultural industry (Mittler, 2006). According to reports, climate change is expected to reduce worldwide potato yields from 18 percent to 32 percent (Hijmans, 2003). For instance, in 2016, heat and drought reduced the potato crop in Ontario by 35–50% (Banks & VanOostrum, 2016). These great losses in potato yield are attributed to the impact of heat stress which is directly or indirectly related to physiological processes.

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Reviewing the effects of heat stress on physiological processes such as photosynthesis, dry matter accumulation and partitioning, tuberization (tuber initiation and development, tuber yield and quality), nutritive quality of tubers (composition and antioxidant property), and reproduction/breeding activities are the main objectives of this paper. Finally, methods to increase heat and moisture tolerance will be reviewed, and further steps will be suggested.

## 2. HEAT STRESS ON PHYSIOLOGY AND MORPHOLOGY

Due to the ever changing climate, there has been an increase in the CO<sub>2</sub> levels, resulting in an increase in global air temperature. Because of this, plants' physiological and morphological functions have been adversely affected. The next sections describe the effects on the two most important morphophysiological effects separately.

### 2.1 Photosynthesis

Heat stress has a deleterious impact on plant growth and development, including leaf photosynthesis. The most harmful consequence of heat stress on plants is the degradation of the plant's photosynthetic activity, with the light reaction's (PSII) and the dark reaction's RUBISCO activase enzymes being the most affected (Sun et al., 2017; Wang et al., 2018). The optimal temperature for full plant photosynthesis in a potato crop is 24°C (Fleisher & Timlin, 2006). Heat stress induces reversible photosynthesis reduction; higher heat stress causes irreversible damage to the photosynthetic machinery, resulting in greater plant growth suppression (Aldubai et al., 2022; Song et al., 2014).

Heat stress reduces the photosynthesis rate in heat tolerant and heat sensitive potato cultivars, according to (Aien et al., 2017). At high temperatures, these researchers also

saw a decrease in stomatal conductance. Chlorophyll is a key component of the photosynthesis process, which is influenced by high temperatures (Sadura et al., 2020; Yuan et al., 2021). The effect of heat stress on the level of chlorophyll in potatoes, on the other hand, is unpredictable. Previous research revealed that when temperatures were high, total chlorophyll decreased and the ratio of chlorophyll (a/b) increased (Aien et al., 2017; Hancock et al., 2014).

In potato plants, high temperatures have been shown to reduce whole-canopy photosynthesis (Obiero et al., 2020). Changes in leaf area, as well as the rate of net photosynthesis (Pn) per unit leaf area, are included in whole canopy measurements. Strong evidence is also that high temperatures affect potato leaf area development (Fleisher & Timlin, 2006). The reaction of Pn to high temperatures differed between younger and older leaves. The photosynthetic rate of older leaves was more likely to decrease, whereas the rate of younger leaves either increased or remained unchanged (Lemoine et al., 2013). The importance of these differences for overall plant carbon dynamics, and thus tuber growth, will be determined by the relative contributions of young and old leaves, as well as the impact of known changes in leaf area and canopy structure on light receipt by leaves of various ages (Obiero et al., 2020). A switch to high temperature increased the net photosynthesis of a young, fully grown leaf, which had previously declined. This was most likely due to stomatal reactions, and it raises the question of how important atmospheric humidity and leaf water status are in affecting potato sensitivity to high temperatures (Obiero et al., 2020). Strong visible light and heat are two abiotic stressors that can damage photosystem II. The most significant damage occurs

in the reaction center-binding D1 protein under both stressors. Phosphorylation and dephosphorylation of the D1 protein as well as the binding of the extrinsic PsbO protein to Photosystem II cause the most significant damage (Yamamoto et al., 2008). Since blocking this electron channel during anaerobiosis was found to dramatically increase the photoinactivation of PS I, it appears that heat-stress-induced PS I electron transport independent of PS II constitutes a protective mechanism in potato crops (Havaux, 1996).

## **2.1 Dry mater accumulation and photoassimilate partitioning**

Potatoes have sink organs in the form of underground stolons, and source organs in the form of leaves (Golovko & Tabalenkova, 2019; Hastilestari et al., 2018). Sucrose in mesophyll cells initiates photosynthesis, which is carried to companion cells and the sink via sieve elements (Jensen et al., 2016). Temperature affects carbon transit to sink organs in the potato, and at high temperatures, less absorbed carbon is incorporated into the tubers. As a result, tuber yield is determined by the relative sink strength and assimilate translocation from leaves (Ludewig & Sonnewald, 2016). To enable continued growth and development, sucrose is unloaded and then degraded into hexoses by sucrose synthases (SuSy) (Hastilestari et al., 2018). SuSy overexpression in transgenic plants increases starch accumulation in tubers, implying that SuSy is involved in sink strength determination (Baroja-Fernández et al., 2009). Carbon accumulation at phloem unloading sites limits the carbon supply to tubers and weakens the sink during heat stress (Durand et al., 2018). Apart from sucrose, various phloem mobile compounds are synthesized in leaves and transferred to the sink to limit tuberization under favorable conditions (Abelenda et al., 2019).

For better knowledge and understanding of the source-sink regulation at elevated temperature, a tissue-specific heat exposure is administered to potato plant (Hastilestari et al., 2018). Photosynthesis and SP6A were influenced by below-ground heat stress, whereas tuberization was inhibited by above-ground heat stress. These findings show that tuberization under heat stress is regulated by bidirectional signaling between source and sink organs (Hastilestari et al., 2018).

Heat stress reduces tuber production, tuber dry matter, and net absorption rate considerably (Aien et al., 2017; Busse et al., 2019; Ferreira et al., 2014). Temperatures of 14°C to 22°C stimulate tuberization, boost dry matter partitioning, and inhibit haulm development (Rykaczewska, 2013). High temperature, on the other hand, increases dry matter partitioning to the haulm, shoot growth, root growth, and tuber yield reduction by reducing tuber size and quantity (Trapero-Mozos et al., 2018). It has been shown that rise in temperature leads to increased percentage of leaf dry matter and decreased percentage of tuber dry matter. They also saw a similar pattern in the dry weight of leaves and tubers (Hancock et al., 2014). During tuber initiation, high temperatures cause the respiration rate to increase, wasting up energy and lowering tuber set. High temperatures during bulking slow down tuber bulking, which results in yield losses. A high respiration rate mid-season or later may result in the development of a second set of tubers that never grow in size (Ewing, 1981; Finckh et al., 2006).

## **3 HEAT STRESS EFFECT ON TUBER FORMATION AND YIELD**

### **3.1 Tuber initiation and development**

The night temperature is critical for potato tuber initiation and development (Kim & Lee,

2019). Even if the daytime temperature is 30–35 °C, potatoes can produce a satisfactory yield if the nighttime temperature is below 18 °C. Even when the daytime temperature is 25–27°C, there is little tuberization when the nighttime temperature exceeds 22°C. It was also investigated that respiration can absorb 35% of the  $14_c$  initially ingested during tuber formation, indicating a high efficiency of carbohydrate polymer storage in the form of starch. So, when it comes to heat tolerance in potatoes, the minimum night temperature is more important than the maximum day temperature (Muthoni & Kabira, 2015). Temperatures above the optimum significantly impact various physiological characteristics, including tuberization (Rykaczewska, 2013).

Tuber development begins with the suppression of longitudinal growth and the extension of radial growth. Tuberization in potatoes is a complex biochemical process involving numerous metabolic pathways and molecular and hormonal signaling (Dutt et al., 2017; Kondhare et al., 2020). Photoperiod (Zhou et al., 2017), growth hormones (Kolachevskaya et al., 2018), and night temperature all play a role in tuberization (Rykaczewska, 2015). Hence, potato tuber initiation and development is sensitive to high temperatures, and the asymmetric increase in day and night temperatures poses a difficulty.

Temperatures for tuber formation are lower: tuber induction is best at 15°C, initiation at 22°C, and setting at 15°C (Struik, 2007). As a result, the time when the heat-sensitive sink (i.e., tuber) develops is essential for potato yield and tuber size. In a recent independent experiment to investigate the effects of high temperature and higher  $CO_2$ , high temperature (35°C) significantly reduced tuber growth compared to normal temperature (25°C) at the tuber initiation

stage in both low (Low $CO_2$ ) and elevated (Elev $CO_2$ )  $CO_2$  settings. Tuber DMAR was reduced by 82 percent when temperatures were high and  $CO_2$  levels were low (Chen & Setter, 2021).

### 3.2 Tuber Yield and Quality

Heat-stressed plants are partially immature, as a result of secondary growth. The size of a plant's assimilation region was determined by the duration of heat stress and the moisture content of the soil (Tang et al., 2018). Secondary tuberization is linked to secondary growth of the above-ground section of the plant in potatoes (Rykaczewska, 2017). High temperatures, regardless of water supply, cause second-growth in potato tubers, while dryness is not required to cause second-growth (Chang et al., 2018). Heat stress had a negative impact on potato tuber yield during the growing season. When heat stress influences plants in the II phase, the effect will be more pronounced. When the time of heat stress treatment on potato plants was delayed the negative effect on the yield of tubers became minimum (Rykaczewska, 2017).

High temperatures acting later in plant development had a detrimental impact on tuber physiological abnormalities (Figure 1), including deformations, sprouting, tubers sprouting in the soil before harvest, and tubers that were physiologically younger (immature). If potato plants are planted in warmer seasons, immature tubers frequently sprout during growth, a process known as "heat sprouts" or "heat sprouting." More than half of the tubers in the field have the potential to sprout. If potato tubers sprout before or shortly after harvest, the quality and utility of the potatoes is seriously harmed (Mikitzel, 2014; Stark et al., 2020).

One of the most major unpredictable factors affecting potato yields is high

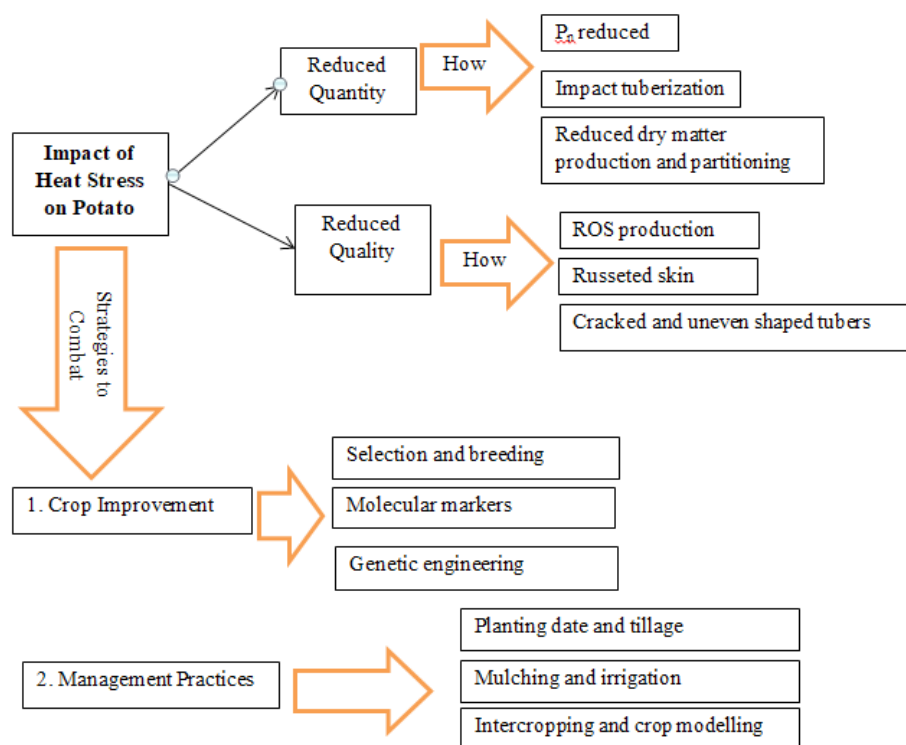


Figure 1. Impact of heat stress on potato and strategies to combat

temperature. Global yields are expected to decline by 18–32% in the 2050s due to the effects of global warming on potato cultivation (Hijmans, 2003). However, it should be noted that the ideal temperature for a potato crop varies depending on the plant's stage of development (Wohleb et al., 2014). Though temperatures between 14 and 22°C at night are ideal during the pre-stolon initiation stage, night temperatures should be around 17°C for proper tuber formation, as high temperatures promote vegetative growth and tuber production falls rapidly (B. Singh et al., 2020). There may not be any tuberization at 25°C and above, whereas potato plants can withstand up to 32°C without significant loss in total biomass production (A Singh et al., 2016).

The physiological impacts of high temperatures on the potato crop are numerous. Reduced early sprouting, unevenly

shaped tubers, increased number of small sized tubers, tuber cracking, bitter and toxic tuber formation, low-quality tubers with lower dry matter, secondary tuber formation, pre-harvest sprouting, irregular skin, necrosis, chlorophyll loss, reduced stem thickness, increased plant height, increased number of small sized leaves, increased concentration of reducing sugars, and increased disease susceptibility are just a few examples (George et al., 2017; B. Singh et al., 2020; Tang et al., 2018).

Furthermore, heat stress produced by excessive soil temperature causes interior brown patches and brown discolouration in the tuber. High soil temperatures produce tuber rot, which damages sprouts, and mulching can help to accelerate this process (Mori, 2015). High temperatures have been linked to increased skin/periderm cell layers, resulting in russeted or cracked tubers with

uneven skin. The greater thickness is related to phellogen's enhanced activity at high temperatures (Molteberg, 2017). Furthermore, the potato tuber moth (*Phthorimaea operculella* Zeller) grows more quickly at higher temperatures (Kroschel et al., 2013).

#### 4. HEATS STRESS EFFECT ON NUTRITIONAL QUALITY

High temperatures alter potato tubers' nutritional profile and secondary metabolism by modifying the content of health-promoting components such as anthocyanin and carotenoids (Fogelman et al., 2019). Even a brief exposure to high temperatures during tuberization can increase the amount of reducing sugars in the tubers and increase stem end chip deformities (Busse et al., 2019). Heat stress also boosts glycoalkoid levels in tubers, making the tuber bitter to consume (Benavides et al., 2017; Uluwaduge et al., 2018). This issue is linked to greater amounts of glycoalkaloid in heat-tolerant potato types (Benavides et al., 2017).

Another independent study found that under high air temperatures, potatoes' total and tuber dry matter content falls significantly (Zhou et al., 2017). By inducing tuber diseases and affecting tuber processing and nutritional quality, high-temperature stress can adversely impair the overall and marketable output of potatoes (Momčilović, 2019).

#### 5. STRATEGIES TO IMPROVE HEAT STRESS TOLERANCE

##### 5.1 Selection and Breeding

Sessile plants are subjected to various climatic challenges, and they have developed various strategies to cope with temperature fluctuations in their environment (Pedroza-Garcia et al., 2022). To secure their survival, they respond to heat stress by undergoing

a complex series of adaptive modifications (Asthir, 2015). To prevent heat stress, plants use a variety of mechanisms, including leaf rotation, leaf rolling, early maturation, transpirational cooling, and changes in membrane lipid compositions (Sadok et al., 2021).

In a heat-stressed environment, the potato may experience oxidative damage. On the other hand, heat-resistant potato types have higher antioxidant enzyme activity to protect the cells. Rao et al., 2018, as cited in (B. Singh et al., 2020). Potato breeding for heat tolerance can be enhanced by a thorough understanding of the many processes governing ROS scavenging enzymes such as superoxide dismutase, ascorbate peroxidase, and catalase in response to heat stress, Rao et al., 2018 as cited in (B. Singh et al., 2020)

Heat tolerance is influenced by stress response expression. A substantial number of genes show differential expression following heat stress treatment in important food crops and model plants, according to previous research (Aldubai et al., 2022). Many heat responsive genes in potatoes have been found thus far using various methods. (Anupama Singh et al., 2015) used a microarray chip with 39,031 potato genes to find genes that cause tuberization at high temperatures in two different potato cultivars.

Many wild solanum species are resistant to abiotic stressors such high temperatures, frost, drought, salt, severe rains, and heavy metals (Imran et al., 2021). There are various wild heat-tolerant potato species that can be used in breeding programs to create heat-tolerant lines, including *S. kurtzianum* and *S. sogarandinum*, *S. chacoense*, *S. stoloniferum*, *S. demissum*, and *S. berthaultii* (Guedes et al., 2019). These wild species' genes can be employed to boost potato crops (Stokstad, 2019). Transfer of genes from other sexually

compatible wild species has been the most prevalent strategy used in the last century to generate abiotic stress tolerant variations (Stokstad, 2019). The majority of today's farmed potato cultivars are tetraploid, although some wild potato species can withstand extreme temperatures (Guedes et al., 2019). As a result, breeding with many wild species might be difficult due to ploidy differences (Bethke et al., 2017).

## 5.2 Management Strategies

In potato, genetic improvement alone is not enough to maximize crop production and productivity. Because current potato cultivars have a limited genetic background, they have poor abiotic stress tolerance (Tao et al., 2012). As a result, in order to cope with a variety of climatic challenges, it is required to modify present commercial cultivars in accordance with the requirements.

In order to successfully grow the potato crop under abiotic stress, better potato cropping systems are required. Superior genotypes, in combination with appropriate agronomic measures including planting date, soil management, tillage, mulching, irrigation, and intercropping, can help potatoes deal with abiotic challenges (Muthoni & Kabira, 2015; Resop et al., 2016). Farmers should modify the planting dates to increase potato yields in different climates (Franke et al., 2020).

Early sowing and increased usage of inorganic nitrogen can help prevent yield loss in potatoes (Bewket, 2018). Tillage can help with aeration, infiltration, and nutrient uptake in the soil. Soil moisture and temperature are directly related to potato yield and quality, which can be maintained by utilizing organic/biodegradable mulches (Bavougian & Read, 2018). One of the best approaches to reduce yield loss due to

heat stress is to vary the sowing season in response to climate change. Plants adapt to heat stress by changing stress proteins' expression, antioxidant defences, osmoprotectants, signaling pathways, and transcriptional regulation (Rasul et al., 2017; Xalxo et al., 2020).

## 6. FUTURE DIRECTIONS

Climate change is posing a threat to long-term potato production. With the creation of heat-tolerant potato types, this effect can be decreased. According to available information, photosynthesis, respiration, carbon partitioning, and hormonal signaling all affect tuber production during heat stress. Because potato tuberization is a complicated polygenic trait, using typical breeding approaches to fight heat stress is difficult. Furthermore, developing effective pure lines takes a long period in breeding programs. Scientists all across the world are working to not only expand potato production in tropical areas, but also to obtain a consistent tuber output under variable environmental conditions.

Apart from breeding, genetic engineering and genome editing techniques are now widely used to generate better crops in the future. Traditional and molecular breeding cycles, transgenic development, and genome editing procedures all require understanding of heat responsive genes.

Most existing cultivars' wild relatives are reservoirs of beneficial genes that could play a key role in crop improvement. The genus *Solanum* contains a number of wild species, the majority of which bear tubers and are widely scattered around the world. These have a wide variety of pest and disease resistance, as well as resistance to various abiotic stresses such as high temperatures, frost, drought, salt, heavy rains, heavy metals, and so on.

*S. chacoense*, *S. stoloniferum*, *S. demissum*, *S. berthaltii*, *S. kurtzianum*, and *S. soganandinum* are some of the heat-tolerant potato species that can be used in breeding programs to develop heat-tolerant lines. However, knowing the genes involved in tuberization at high temperatures isn't adequate because it's a multigenic characteristic. Understanding the specific molecular networking that occurs in response to heat stress would be a significant step forward.

## 7. CONCLUSION

Heat stress drastically lowered crop yields, and the impact of this stress is anticipated to grow in the future. Heat stress limits potato output since this crop is extremely sensitive to high temperatures, especially during tuber formation. Tuberisation in response to heat stress is a multigenic feature that is difficult to research and measure using traditional methods. With the use of advanced biotechnological methods, we hope to fully understand the mechanism of tuberculosis in the coming years.

However, using functional genomics, several possible candidate genes in potato have been found, opening up new possibilities for the production of heat-resistant variants. There is a pressing need to extend the database of heat stress-related genes in potatoes, as well as our understanding of how these genes express themselves in response to heat stress. In addition, well-known heat-tolerant genes from model plants can be inserted into the potato genome. To better understand the mechanism of heat tolerance by diverse genes, the novel genome editing tool CRISPR-Cas9 should be used in potato. Besides, better agronomic practices and meteorological analysis can aid in increasing potato production in high temperatures. In today's world, the best strategy to combat heat stress is to use a combination of methods.

Moreover, better agronomic practices and meteorological information can assist in increasing potato production at higher temperatures. In today's situation, combining traditional and new biotechnological procedures is the most effective strategy to prevent heat stress.

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# MANUSCRIPT PREPARATION GUIDELINES FOR AUTHORS

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Scott G, Best R, Rosegrant M and Ringler C (2000) Global projection for root and tuber crops to the year 2020. *Food Policy* **25**(5): 561-97

Anonymous (2010) Agribusiness in India: green shoots. *Economist* **394**(13-19 March): 65-66

Chakravarty C and Pandey B (2005) Growing roots in farmlands: an interview with Ms Indra Nooyi, worldwide president and CFO, PepsiCo. *Econ Times* 29 August 2005

##### *Online sources*

FAO (2008) Potato world: Africa-international year of the potato 2008. Food and Agriculture Organisation, Rome. <http://www.potato2008.org/en/world/africa.html>, 31 December 2008

Hirtle PB (2008) Copyright renewal, copyright restoration, and the difficulty of determining copyright status. *D-Lib Magazine* **14**(7-8), DOI:10.1045/july2008-hirtle

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E-Views (2006) E-Views quantitative software. <http://www.eviews.com>, 28 September 2006

##### **Book and book chapter**

Guenther J (2001) The International Potato Industry. Woodhead Publishing Limited, Cambridge: 312p, ISBN-13: 978 1 85573 465 4

Adiyoga W and Norton GW (2009) Costs and benefits of Bt potato with resistance to potato tuber moth in Indonesia. In, Projected Impacts of Agricultural Biotechnologies for Fruits and Vegetables in the Philippines and Indonesia. Norton GWH (ed), Los Banos, Philippines: 105-40

##### **Annual report, bulletin or working paper**

CPRI (2010) Annual report 2009-10. Central Potato Research Institute, Shimla, India: 203p

Chand R (2003) Government intervention in food grain markets in the new context. National Centre for Agricultural Economics and Policy Research, New Delhi. Policy paper-19: 118p

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##### **Conference presentation**

Haq I, Farooq K and Mahmood MM (2008) Screening of potato genotypes for late blight resistance/ tolerance in Pakistan. Poster presented in Global Potato Conference-2008, New Delhi, 9-12 December 2008

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##### **Thesis**

Kaur RJ (2004) Effect of nitrogen management through organic and inorganic sources in potato. Department of Agronomy, Punjab Agricultural University, Ludhiana, India, Ph.D. thesis: 99p

### Encyclopaedia or dictionary

Kinni TB (2004) Walt Disney (1901-1966): founder of the Walt Disney company. Encyclopaedia of Leadership. Sage Publications, Thousand Oaks, CA: 1: 345-49

Cowie AP (1989) Oxford Advanced Learner's Dictionary, 2<sup>nd</sup> ed. Oxford University Press, Oxford

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| Cubic centimetre | cm <sup>3</sup> | Millilitre | ml              |
| Gram             | g               | Minute     | min             |
| Hectare          | ha              | Nanometre  | nm              |
| Kilogram         | kg              | Second     | s               |
| Litre            | l               | Square cm  | cm <sup>2</sup> |
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