agronomy

MDPI

Article

Study on Morphological, Physiological Characteristics and Yields of Twenty-One Potato (*Solanum tuberosum* L.) Cultivars Grown in Eastern Sub-Himalayan Plains of India

Santanu Das [1], Biplab Mitra [1], Satish Kumar Luthra [2], Asok Saha [1], Mohamed M. Hassan [3,*] and Akbar Hossain [4,*]

[1] Department of Agronomy, Uttar Bangla Krishi Viswavidyalaya, Pundibari, Cooch Behar 736 165, West Bengal, India; sd.das28@gmail.com (S.D.); bipmitra@yahoo.com (B.M.); asok.ubkv@gmail.com (A.S.)
[2] ICAR-Central Potato Research Institute, Regional Station, Modipuram, Meerut 250 110, Uttar Pradesh, India; skluthra@hotmail.com
[3] Department of Biology, College of Science, Taif University, P.O. Box 11099, Taif 21944, Saudi Arabia
[4] Bangladesh Wheat and Maize Research Institute, Dinajpur 5200, Bangladesh
* Correspondence: m.khyate@tu.edu.sa (M.M.H.); akbarhossainwrc@gmail.com (A.H.)

Abstract: The present study was conducted in the eastern sub-Himalayan plains of West Bengal, India, to evaluate 21 potato cultivars (including table- and processing-type) and assess their suitability in terms of improved physiological responses, yield performances, stability and profitability. A significant difference in various growth attributes, i.e., plant height, number of stems per plant, leaf area index (LAI), dry matter (DM) accumulation, and crop growth rate (CGR), was noted amongst different cultivars. Significant variation was also observed in net photosynthesis rate (NPR), transpiration rate (TR), and stomatal conductance rate (SCR) recorded at various stages of growth. Amongst all the cultivars, 'Kufri Chipsona-4' showed the highest SCR at both 60 and 80 days after planting (DAP), while 'Kufri Pokhraj' had the highest NPR at both 60 and 80 DAP. However, the highest TR was achieved with 'Kufri Chipsona-3'and 'Kufri Surya' at 60 and 80 DAP, respectively. 'Kufri Pukhraj' and 'Kufri Himsona' achieved the maximum and minimum tuber bulking rate (TBR) values at initial growth stages (upto 60 days), respectively; however, 'Kufri Arun' and 'Kufri Surya' had significantly higher TBRs during the later part of growth (after 60 days to maturity), leading to higher tuber yields amongst the medium maturing cultivars. Among the 21 cultivars, 'Kufri Arun' showed the maximum total tuber yield (35.52 t/ha), followed by 'Kufri Pukhraj' (33.54 t/ha) with higher marketable grade tubers. In terms of production economics, 'Kufri Arun' achieved the maximum net return (USD 2137.4) and B:C (benefit:cost) ratio (2.17), suggesting the suitability of this cultivar in the eastern sub-Himalayan plains of West Bengal. The early maturing 'Kufri Pukhraj' and processing variety 'Kufri Chipsona-3' also showed their suitability in terms of net returns and B:C ratio. The heat-tolerant variety 'Kufri Surya' also achieved a tuber yield of 31 tha^{-1} with satisfying net return (USD 1596.9) and B:C ratio (1.88), suggesting the suitability of this cultivar in this region under terminal heat stress. However, the stability analysis showed that the cultivars 'Kufri Khyati' and 'HPS II/67' were the most stable in terms of additive main effect and multiplicative interaction (AMMI) stability value (ASV) and yield stability index (YSI), respectively.

Keywords: potato; growth attributes; net photosynthesis rate; production economics; tuber yield

Citation: Das, S.; Mitra, B.; Luthra, S.K.; Saha, A.; Hassan, M.M.; Hossain, A. Study on Morphological, Physiological Characteristics and Yields of Twenty-One Potato (*Solanum tuberosum* L.) Cultivars Grown in Eastern Sub-Himalayan Plains of India. *Agronomy* **2021**, *11*, 335. https://doi.org/10.3390/agronomy11020335

Academic Editor: Paul C. Struik

Received: 15 January 2021
Accepted: 10 February 2021
Published: 13 February 2021

1. Introduction

Potato (*Solanum tuberosum* L.) is one of the most important commercial crops that contributes to food security on a global scale, due to its high yield per unit of cropland and time [1]. Globally, it ranks fourth in importance among food crops after rice, wheat and maize. The potato production in India during 2017–18 was 51.31 million tonnes, from 2.14 million ha area, with a productivity of 23.97 t ha^{-1} [2]. In West Bengal, the total production was 12.78 million tonnes from an area of 0.43 million hectares, with a productivity of 29.72 tha^{-1}, reflecting the large contribution of this state to the potato production of the country. The sub-Himalayan plains are one of the important potato growing regions of West Bengal. In this part of West Bengal, some farmers grow an early crop of potato (75 days duration) to get a premium price before bulk harvesting takes place. Cultivar selection is very important for growers intending to market their quality produce [3]. The farmers need varieties that show high yield performances over a wide range of environmental conditions, and also over the years. Potato crops involve huge financial investments in terms of fertilizer and plant protection chemicals, and so the predictability of the yields of genotypes needs to be properly assured in order to protect the interest of the farmers. Moreover, genotypes show the varying extent of the phenomenon of phenotypic expressions under different environmental conditions resulting in crossover [4]. This crossover performance of the genotypes under different environmental conditions (two different years) is the consequence of the differential responses of the genotypes to the different environmental factors [5]. This is defined as the genotype × environment (G × E) interaction [6]. The G × E interaction is caused by the differential sensitivities and responses of the genotypes to the target environment [7], which leads to the inconsistent performances of the genotypes over the environments, and the efficiency of the selection of superior genotypes is limited due to this factor. It is for this reason that the genotypes of the different crops are evaluated over diverse environments, so as to test their adaptability. Several methods are used to assess the G × E effect and the stability of crop production performances. One of the most effective of such methods is the use of multiplicative models, which include the additive main and multiplicative interaction (AMMI) [8,9].

In India, the concerted breeding efforts of potato varietal improvement programmes at the Central Potato Research Institute (CPRI) have led to the development of 65 improved potato varieties, and presently 23 varieties occupy nearly 95% of the total potato area in India [10]. Out of these 65 varieties developed, 33 possess resistance to different biotic and abiotic stresses, and 8 varieties are suitable for processing purposes. All these potato varieties actually fall into three maturity groups, i.e., early, medium and late. There is an increasing demand for new potato varieties with satisfactory yields and processing characteristics. French fries and potato chips are the most important processed potato products, for which suitable varieties need to be identified to meet the domestic requirement as well as the export market. In India, potatoes have been utilized largely for consumption as fresh potatoes, and the major part of potato harvest goes towards domestic consumption, whereas in developed countries, table potato utilization is merely 31%, the rest being frozen French fries (30%), chips and shoestrings (12%), and dehydrated products (12%) [11]. The processing of potatoes in the country was not in vogue until the 1990s, and with the commencement of organized processing by multinationals and indigenous players, the potato processing industry has grown many times over. In India, the potato processing industry has shown tremendous growth during the past decade, and now, nearly 7.5% of potatoes are processed.

Potato production has significantly increased in India in recent years, making it the second-largest potato-producing country in the world [12]. Moreover, the numbers of processing industries and potato products are increasing with the demand for specific varieties. Despite the increasing demand for the processing of quality potatoes, the availability of suitable raw material for the processing industry is scant. Therefore, it is important to identify potato genotypes that possess traits that meet the challenges of frequently changing market and production circumstances [13]. The varietal features of short-day adaptation, medium maturing time, moderate resistance to late blight, and a slow rate of degeneration are desirable traits for potatoes in this zone [2,14]. The screening of potato genotypes with improved processing characteristics and wide adaptability is important to all segments of the potato industry. Keeping this aspect in the background, the present study was conducted to evaluate 21 potato genotypes, including some processing cultivars for gaining higher marketable yields with greater stability, and improved physiological characteristics and profitability.

2. Materials and Methods

2.1. Location of the Observation

The experiment was conducted during the winter season (as the main crop) in two consecutive years (2016–2017 and 2017–2018) at the Institutional Farm of Uttar Bangla Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal, India, which falls under the category of eastern sub-Himalayan plains (28°58′86″ N latitude and 81°66′73″ E longitude, at an elevation of 42 m above mean sea level).

2.2. Agro-Climatic Conditions

The climate of the region is subtropical in nature with distinctive characteristics of high rainfall, high humidity and prolonged winter. There are broadly two dominant seasons in a year: extended winter or dry rabi season, and a long rainy season, i.e., wet season. The temperature range of this area varies from a minimum of 7.1–8.0 °C to the maximum of 24.8–32.2 °C. During the experimental period, the maximum and minimum temperatures fluctuated between 23.9 and 30.1 °C and 8.06 and 15.4 °C in 2016–2017, and between 22.9 and 30.2 °C and 7.5 and 16.3 °C in 2017–2018, respectively. In general, there was a gradual drop in temperature from November to January in both the years that favored the formation and development of tubers. The rainfall during the experimental period (November to March) was 48.00 mm (2 rainy days) and 4.71 mm (2 rainy days) in 2016–2017 and 2017–2018, respectively. The overall weather conditions were quite congenial for the growth and development of potato during both years of experimentation. The overall soils in this part of the country are usually low in N, medium in P and low in K. The experimental soil's pH was 5.74, with organic carbon 0.664%, cation exchange capacity 17.95 me/100 g, mineralizable nitrogen 116.82 kg/ha, available phosphorus 17.32 kg/ha and available potassium 84.68 kg/ha.

2.3. Experimental Materials and Design

The experimental materials comprised 21 potato cultivars: 8 early maturing ('Kufri Chandramukhi' (V_1), 'Kufri Pukhraj' (V_2), 'Kufri Ashoka' (V_3), 'Kufri Khyati' (V_4), 'HPS I/67'(V_5), 'HPS II/67' (V_6), 'HPS 7/67' (V_7), 'Pimpernel' (V_8)); 8 medium maturing ('Kufri-Joyti' (V_9), 'Kufri Kanchan' (V_{10}), 'Kufri Megha' (V_{11}), 'Kufri Himalini' (V_{12}), 'Kufri Gird-hari' (V_{13}), 'Kufri Arun' (V_{14}), 'Kufri Giriraj' (V_{15}), 'Kufri Surya' (V_{16})) and 5 processing-types ('Kufri Chipsona-1' (V_{17}), 'Kufri Chipsona-3' (V_{18}), 'Kufri Chipsona-4' (V_{19}), 'Kufri Frysona' (V_{20}) and 'Kufri Himsona' (V_{21})).

The trials were laid out in a randomized complete block design with three replications. The preceding crop in the rotation was rice. Each cultivar was planted in a thoroughly prepared field with fine tilth after the harvesting of rice. The net plot size was 4.0 m × 4.5 m, comprising eight rows with 50 (between rows) × 15 (within rows) cm^2 plants spacings.

2.4. Experimental Procedure

Sprouted seed tubers of 40–45 mm size were planted in the third week of November of both the years under experimentation. The recommended dose of fertilizer (N:P:K) was applied to a ratio of 125:100:125 $kgha^{-1}$. Half of the nitrogen, along with a full dose of P and two-thirds of the K were applied as basal. The remaining nitrogen was given in two equal measures, one as a first topdressing at 21 days after planting (DAP) and the remaining at 42 DAP, along with one-third of the K. After manual weeding just before the first topdressing, the crop was earthened to promote tuber growth and to keep the tuber free from unwanted exposure to sunlight. Mancozeb 75% wettable powder (WP) and Dimethomorph 50% WP were applied alternatively at intervals of 10–12 days up to 80 DAP starting from 25 DAP, in order to protect the crop against late blight and other fungal diseases. The crop was dehaulmed at 90 DAP.

2.5. Data and Their Recording Procedures

The data were recorded on the following characteristics: plant height, number of stems/plant, dry matter accumulation of shoot, leaf area index (LAI), crop growth rate (CGR), tuber bulking rate, total tuber yield (t/ha), marketable yield (%), grade-wise tuber yield and production economics, in addition to physiological responses, i.e., net photosynthesis rate (NPR), transpiration ratio (TR) and stomatal conductance rate (SCR).

The plant height of the main stem from the ground level to the apical bud (leaf apex) was measured with the meter scale, and the total number of stems per plant of the tagged plants was counted at 80 DAP. The observations of dry matter accumulation, LAI and CGR were taken at periodical intervals. The observations of periodical physiological parameters, i.e., NPR, TR and SCR, were taken in the upper leaf (2nd leaf from top), the middle leaf (6th leaf from top) and the lower leaf (2nd leaf from bottom) with a Handheld Photosynthesis System Model Cl-340, manufactured by CID BioScience, Camas, WA USA. To estimate tuber yield, 2 × 2 m areas of each plot were harvested separately, and the tubers were then shade dried for a period of 3 days and the weight was taken for each treatment separately before packaging. The harvested tubers were divided into various grades [15] based on their weights (<40 g, 41–60 g, 61–80 g, 81–100 g and >100 g) for better marketability.

2.6. Estimation of Production Economics

Production economics, i.e., net return and B:C ratio, were calculated by taking into account the prevailing market price of inputs and the farm gate price of potato tubers prevailing during harvest time at the locally regulated market under the control of the West Bengal Government. The prices of all the processing-type cultivars were taken as USD 146.3 and USD 161.7 per ton during 2016–2017 and 2017–2018, respectively. Prices of USD 107.8 and USD 115.5 per ton were taken for the rest of the cultivars during 2016–2017 and 2017–2018, respectively, except the Pimpernel, which fetched USD 123.2 and USD 130.9 per ton in 2016–2017 and 2017–2018, respectively, due to its demand at the local market.

2.7. Statistical Analysis

The data were subjected to pooled analysis for estimating the variability [16] using the software SPSS version 20.0 (Statistical Package for Social Sciences). The yield data were analyzed on an individual year basis and pooled basis, as per the RBD design. The analysis of all the data was performed with the help of the analysis of variance (ANOVA) technique for RBD. The least significant difference test was used to compare the effects of treatments at the 5% level of significance. The mean values were judged by the Duncan Multiple Range Test (DMRT) using SPSS version 20.0. Excel software was used to draw various figures. Data for two years were treated as two different environments. The additive main effect and multiplicative interaction (AMMI) model was used to determine the stability of the genotypes across the two environments. The parameters used for stability analysis were as follows.

2.7.1. AMMI Stability Value (ASV)

According to Purchase et al. [17], in the AMMI model, the ASV is the difference between the coordinate point and the origin in a two-dimensional scatter diagram representing IPCA1 scores against IPCA2 scores. Because the IPCA1 score makes more contribution to the G × E interaction sum of the squares, a weighted value is needed. This weight is calculated for each genotype and each environment according to the relative contributions of IPCA1 and IPCA2 to the interaction sum of the squares, as follows:

$$ASV_i = \sqrt{\left[\frac{SS_{IPCA1}}{SS_{IPCA2}}(IPCA1Score)\right]^2 + (IPCA2Score)^2} \quad (1)$$

where $\frac{SS_{IPCA1}}{SS_{IPCA2}}$ is the weight given to the IPCA1 value by dividing the IPCA1 sum of squares by the IPCA2 sum of squares. The larger the IPCA score, either negative or positive, the more specifically adapted a genotype is to certain environments. Smaller IPCA scores indicate a more stable genotype across environments.

2.7.2. Yield Stability Index (YSI)

For the selection of a genotype, stability should not be the only parameter, as the most stable genotype might not necessarily give the best yield performance [18,19]. Therefore, it is necessary to integrate both mean yield and stability into a single selection index. As such, the various authors and scientists proposed different selection criteria for the simultaneous selection of yield and stability [20,21]. In this context, the rank of ASV and the rank of the mean performance of a character is considered. The lowest ASV value occupies rank one, while the highest mean value of a characteristic occupies rank one, and both the ranks are summed into a single selection index of stability, called the yield stability index (YSI), which considers the most stable high-yielding genotype.

3. Results and Discussion

3.1. Plant Height, Stems Number, DM Production, LAI and CGR

A significant difference in the various growth attributes of different potato cultivars was noted. Among the cultivars, 'Kufri Arun'(V_{14}) showed the highest plant height (66.47 cm) followed by 'Kufri Chipsona-4' (V_{19}) (64.90 cm), and the lowest was 'Kufri Himsona'(V_{21}) (31.07 cm). 'HPS I/67'(V_5), 'Kufri Arun' (V_{14}) and 'Kufri Chipsona-4' (V_{19}) had the highest plant heights amongst the early, medium and processing-type cultivars, respectively, at 80 DAP (Figure 1). The variations in plant height among the different genotypes might be due to genetic and inherent characteristics. The number of stems per plant was significantly higher in 'Kufri Ashoka' (V_3) (4.33) among all the cultivars; 'Kufri Chipsona-3' (V_{18}) had the highest number of stems per plant amongst the processing-type cultivars (Figure 2). A higher number of stems is a desirable morphological characteristic as it builds early soil coverage and a greater photosynthetic area. Though it varies from cultivar to cultivar, a higher number of stems per plant may contribute to a greater number of tubers per plant as well. The number of main stems was positively correlated with tuber number and negatively correlated with individual tuber weight [22]. Despite the higher number of stems in 'Kufri Ashoka' (V_3) in our experiment, the tuber yield was not so higher, probably due to the lower individual tuber weight.

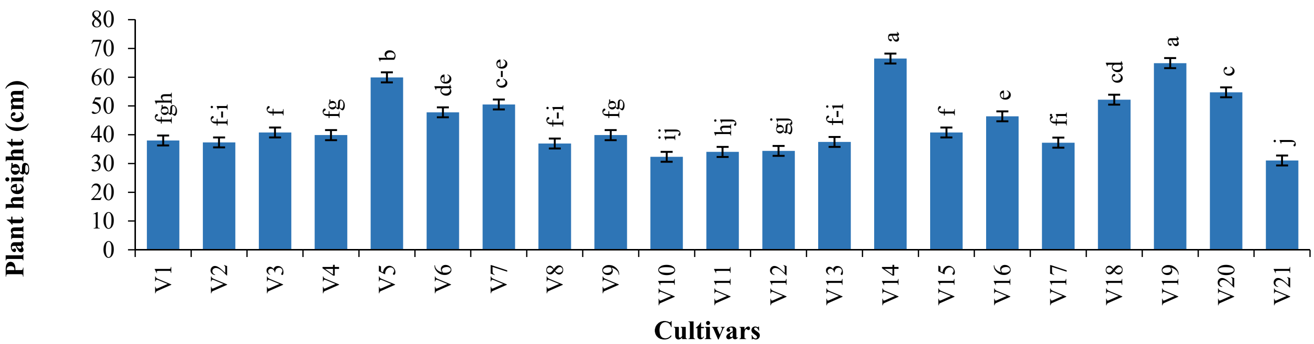

Figure 1. Plant height of different potato cultivars (two years pooled data); values with different lower case letters are significantly different between each other at the 5% level of significance ($p \leq 0.05$); vertical bars represent the standard error of mean values.

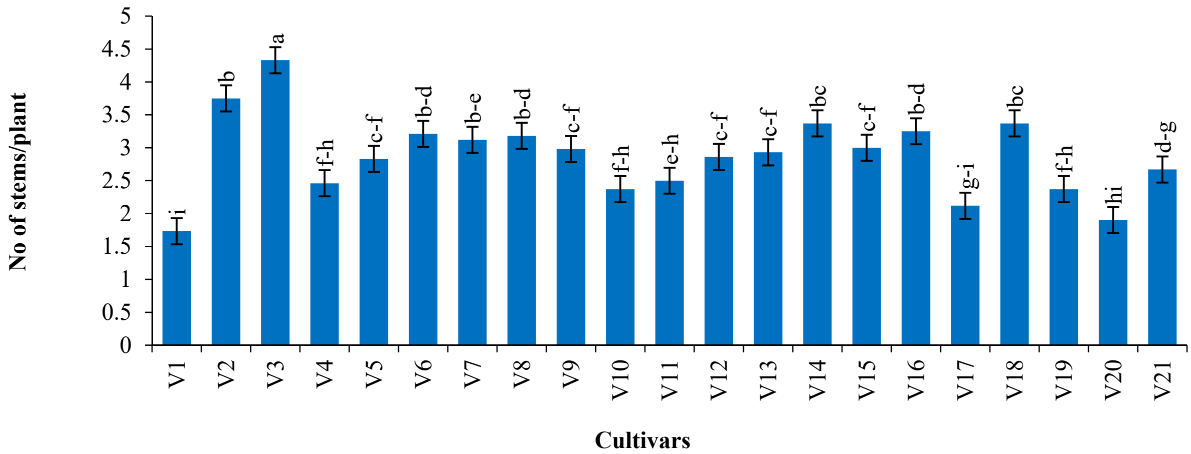

Figure 2. The number of stems/plants of different potato cultivars (two years pooled data); values with different lower case letters are significantly different between each other at the 5% level of significance ($p \leq 0.05$); vertical bars represent standard error of mean values.

Periodical observations of shoot dry matter (DM) accumulation and leaf area index showed significant variations between different cultivars. Amongst the early and medium-duration cultivars, 'Kufri Pukhraj' (V_2) and 'Kufri Arun' (V_{14}) produced the maximum shoot dry matter, at 60 and 80 DAP, respectively (Table 1). Again, in the processing-type cultivars, 'Kufri Chipsona-3' (V_{18}) (219.19 g/m^2) had the maximum dry matter of shoots at 60 DAP, whereas 'Kufri Chipsona-4' (V_{19}) (176.81 g/m^2) had the highest DMA, at 80 DAP. In general, the cultivars 'Kufri Girdhari' (V_{13}), 'Kufri Himsona'(V_{21}) and 'Pimpernel' (V_8) produced much lower shoot DM at 60 DAP compared to the other cultivars, signifying their unsuitability for this region. Again, the processing-type cultivars 'Kufri Chipsona-3' (V_{18}) (219.19 g/m^2) and 'Kufri Chipsona-4' (V_{19}) (204.43 g/m^2), and the table-purpose cultivars 'Kufri Arun' (V_{14}) (228.36 g/m^2) and 'Kufri Pukhraj' (V_2) (203.97 g/m^2) produced greater shoot DM at 60 DAP.

Dry matter accumulation and its partitioning in various plant parts were influenced by the environmental conditions of the locality, along with the overall growth and development characteristics, which were very vital for contributing to potato tuber yield. The accumulated total dry matter through photosynthesis during a given period of growth was partitioned into given plant parts according to the needs of the developmental stages of the cultivars. The shoot dry matter accumulation increased linearly during the crop growth period up to 60 DAP [23], and thereafter the shoot dry matter decreased due to the senescence of the leaves. At 80 DAP, the cultivars retained a fraction of the total dry matter produced at 60 DAP, and this varied from cultivar to cultivar. In our experiment, the cultivars 'Kuri Girdhari' (V_{13}) (95.03%) and 'Kufri Himsona' (V_{21}) (92.13%) retained a maximum percentage of total shoot DM at 80 DAP. Actually, the cultivars 'Kufri Giridhari' (V_{13}) and 'Kufri Himsona' (V_{21}) that produced a lower amount of shoot DM at 60 DAP could retain it at 80 DAP, due to their lower rates of vegetative growth. The shoot DM reduced sharply for cultivars with higher vegetative growth, due to the increased defoliation and senescence at 80 DAP. The difference in the early rate of growth among the cultivars might be attributed to differences in total DM accumulation at the early stage of growth, which manifested later in differences in the total DM at the peak period of growth. The decrease in the DM of the shoots at 80 DAP might be due to the diversion of assimilates towards tubers and the increased photosynthetic rate during the later stage of growth. It was seen from this experiment that around 58–75% of shoot DM was retained, while the rest was diverted to the tubers for most of the cultivars. In general, there was an inverse relationship between haulm and tuber growth at later stages of growth, where the tuber bulking rate was higher. Before tuber initiation, the haulm was the dominating component for assimilation, but at the time of tuber initiation, there was a major diversion of assimilates to the stolon and tuber initials [23].

Table 1. Dry matter (DM) content in the shoot and the tuber bulking rate of various potato cultivars (Pooled data of 2 years).

Cultivars	Growth Parameter					
	DM Content of Shoot (g/m^2)			Tuber Bulking Rate (g/m^2/d)		
	60 DAP	80 DAP	Remaining (%) at 80 DAP	41–60 DAP	61–80 DAP	81–90 DAP
Kufri Chandramukhi	145.49 ^{gh}	84.53 ^{gh}	58.10	26.54 $^{f–i}$	34.42 $^{g–i}$	20.15 $^{d–f}$
Kufri Pukhraj	203.97 ^{b}	127.21 ^{d}	62.37	60.15 ^{a}	49.04 $^{d–h}$	29.54 $^{b–f}$
Kufri Ashoka	152.79 $^{d–h}$	113.57 ^{e}	74.33	36.76 $^{c–f}$	65.96 $^{b–d}$	20.64 $^{d–f}$
Kufri Khyati	148.99 $^{f–h}$	113.53 ^{e}	76.20	35.95 $^{c–g}$	61.31 $^{c–f}$	25.20 $^{c–f}$
HPS I/67	143.86 ^{h}	81.67 $^{g–i}$	56.77	31.18 $^{d–h}$	63.49 $^{c–e}$	21.71 $^{d–f}$
HPS II/67	143.01 ^{h}	81.78 $^{g–i}$	57.18	34.66 $^{c–g}$	68.73 $^{b–d}$	23.67 $^{c–f}$
HPS 7/67	158.44 ^{df}	80.67 ^{hi}	50.92	38.09 $^{b–f}$	87.76 ^{ab}	10.77 ^{f}
Pimpernel	90.80 ^{k}	61.36 ^{j}	67.58	31.14 $^{d–h}$	40.58 $^{e–i}$	25.65 $^{c–f}$
Kufri Jyoti	177.75 ^{c}	105.80 ^{ef}	59.52	28.42 $^{e–i}$	79.02 $^{a–c}$	29.78 $^{b–f}$
Kufri Kanchan	155.83 $^{d–g}$	98.59 ^{f}	63.27	42.95 ^{bc}	23.69 ^{i}	28.53 $^{c–f}$
Kufri Megha	185.26 ^{c}	130.45 ^{d}	70.41	38.10 $^{b–f}$	68.51 $^{b–d}$	38.41 $^{a–d}$
Kufri Himalini	146.37 ^{gh}	106.53 ^{ef}	72.78	30.93 $^{d–h}$	74.10 ^{bc}	42.46 $^{a–c}$
Kufri Girdhari	94.91 ^{k}	90.19 ^{g}	95.03	30.19 $^{d–h}$	26.15 ^{hi}	29.66 $^{b–f}$
Kufri Arun	228.36 ^{a}	161.76 ^{b}	70.84	25.37 $^{g–i}$	97.40 ^{a}	48.16 ^{ab}
Kufri Giriraj	128.40 ^{i}	73.97 ^{i}	57.61	31.69 $^{c–g}$	37.94 $^{f–i}$	31.59 $^{a–e}$
Kufri Surya	159.87 ^{d}	110.79 ^{e}	69.30	18.30 ^{i}	75.18 ^{bc}	50.36 ^{a}
Kufri Chipsona-1	112.83 ^{j}	88.94 ^{gh}	78.83	24.44 $^{g–i}$	41.69 $^{e–i}$	22.13 $^{d–f}$
Kufri Chipsona-3	219.19 ^{a}	143.03 ^{c}	65.25	48.07 ^{b}	57.23 $^{c–g}$	21.61 $^{d–f}$
Kufri Chipsona-4	204.43 ^{b}	176.81 ^{a}	86.49	39.65 $^{b–e}$	40.41 $^{e–i}$	14.97 ^{ef}
Kufri Frysona	179.26 ^{c}	125.71 ^{d}	70.13	41.57 $^{b–d}$	56.80 $^{c–g}$	22.63 $^{c–f}$
Kufri Himsona	96.73 ^{k}	89.12 ^{gh}	92.13	5.06 ^{j}	49.18 $^{d–h}$	21.93 $^{d–f}$

Numbers followed by different lower case letters in a column are significantly different between each other at the 5% level of significance ($p \leq 0.05$), and are otherwise statistically on par.

The leaf area index (LAI) displayed a significant difference at the various stages of growth of different cultivars. At 40 DAP, 'Kufri Chipsona-4' (V_{19}) had significantly higher LAI (1.94), followed by 'Kufri Arun' (V_{14}) (1.81) and 'Kufri Chipsona-3' (V_{18}) (1.80), and the lowest was observed in 'Pimpernel' (V_8) (1.14). 'Kufri Chipsona-3' (V_{18}) had the highest LAI at 60 and 80 DAP, this being statistically on a par with 'Kufri Chipsona-4' (V_{19}). There was a decrease in LAI value for all the varieties at 80 DAP and afterwards (Figure 3).

As leaf surfaces are the primary borders of energy and mass exchange, important processes, such as canopy interception, evapotranspiration, and gross photosynthesis, were directly proportional to LAI. The difference in LAI among the cultivars might be due to their characteristics and acclimatization in the newer environment. The decrease in LAI after 60 DAP was mainly due to the onset of senescence and the ageing of leaves [24]. It was revealed from the study that amongst the cultivars, the processing-type cultivars 'Kufri Chipsona-3' (V_{18}) and 'Kufri Chipsona-4' (V_{19}) showed higher LAI over the other early and medium maturing cultivars. The LAI had a strong correlation with CGR, net photosynthetic rate [25], and final yield. Furthermore, the importance of LAI as a functional trait was further enhanced by the strong relationship it had with the amount of solar radiation intercepted by plants [26], as such interception is one of the most studied eco-physiological processes in crop plants [27].

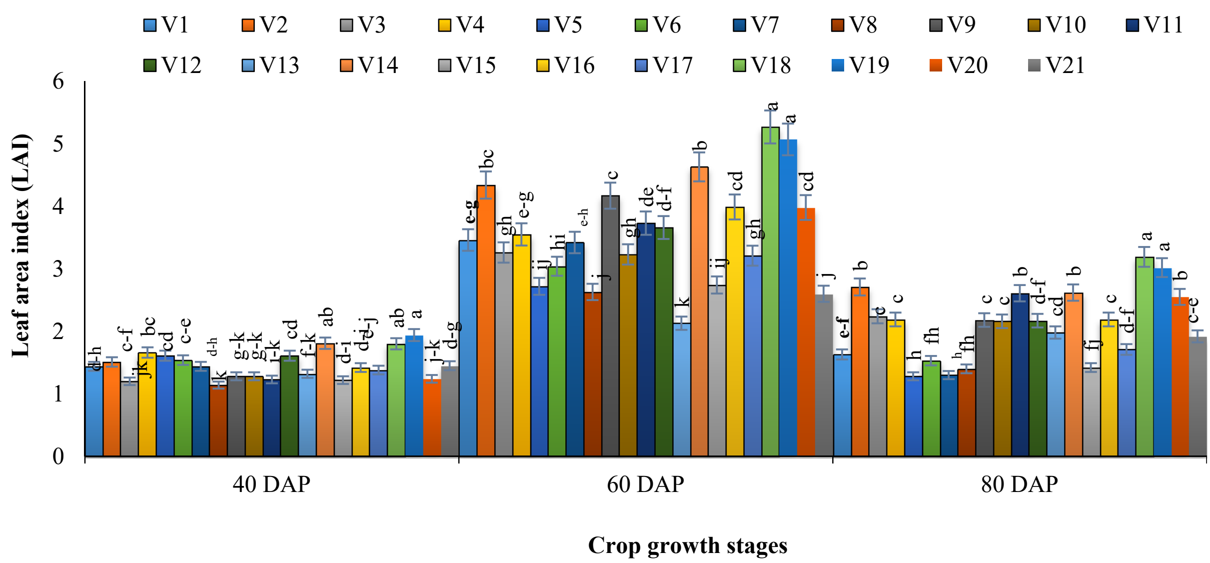

Figure 3. Leaf area index of different potato cultivars during various stages of growth (two years pooled data); values with different lower case letters are significantly different between each other at the 5% level of significance ($p \leq 0.05$); vertical bars represent standard error of mean values.

The crop growth rate (CGR) for all cultivars reached its peak during the period 60–80 DAP. Amongst early and medium duration potato cultivars, 'HPS I/67' (V_5) and 'Kufri Arun' (V_{14}) reached the highest CGR between 40 and 60 DAP (2.81 and 3.66 g/m^2/day), while between 60 and 80 DAP, 'Kufri Pukhraj' (V_2) (7.13 g/m^2/day) and 'Kufri Arun' (V_{14}) (7.09 g/m^2/day) had the higher CGRs (Figure 4). In terms of the processing-types, 'Kufri Chipsona-4' (V_{19}) and 'Kufri Chipsona-3' (V_{18}) showed higher CGR values at 40–60 and 60–80 DAP, respectively. For the cultivars that showed a greater accumulation of shoot DM, the CGR values recorded were higher. The processing-type cultivars 'Kufri Chipsona-4' (V_{19}) and 'Kufri Chipsona-3' (V_{18}) showed higher CGR values due to the higher accumulation of shoot DM. Actually, CGR during the late reproductive period was closely related with yields [28]. This is dependent on radiation-use efficiency, which actually determines how efficiently photosynthates are translocated to the satorage part (tuber). The dry matter accumulation and CGR were significantly greater during the vegetative and potato maturation stages [29]. The dry matter accumulation at the peak vegetative stage showed higher values due to the increased numbers of shoots produced, and again, at the late reproductive stage, due to the higher translocation of photosynthates to the tuber, the tuber weight significantly increased, which ultimately influenced the CGR. However, these differences were relatively inconsistent across cultivars and years during the maturation stage [30].

3.2. Net Photosynthesis Rate, Transpiration Ratio and Stomatal Conductance Rate

Significant variation was observed in net photosynthesis rate (NPR) among the cultivars taken in the experiment (Figure 5). Amongst the early maturing cultivars, 'Kufri Pukhraj' showed the highest NPR at 60 and 80 DAP, while amongst the medium maturing cultivars, 'Kufri Arun' (V_{14}) and 'Kufri Himalini' (V_{12}) had the highest NPR values, on a par with 'Kufri Jyoti' (V_9) and 'Kufri Surya' (V_{16}), at 60 and 80 DAP, respectively. 'Kufri Chipsona-4' (V_{19}) and 'Kufri Chipsona-3' (V_{18}) achieved the highest NPRs at 60 and 80 DAP, respectively, among the processing-type cultivars. It was noted that there was no significant difference in NPR achieved by 'Kufri Chipsona-4' (V_{19}), 'Kufri Frysona' (V_{20}), and 'Kufri Chipsona-3' (V_{18}) at 60 DAP. This difference in NPR could be due to the variation in the response of stomatal conductance to photosynthetic active radiation (PAR). The photosynthetic efficiency of the foliage depends in part upon its content of chlorophyll. It is not the absolute rate of photosynthesis that is important, but rather the relationship between photosynthesis and respiration, termed the net photosynthetic rate, is important for the yield ability. The selection of cultivars with a high net photosynthetic rate will result in a higher yield if all other factors are equal [31].

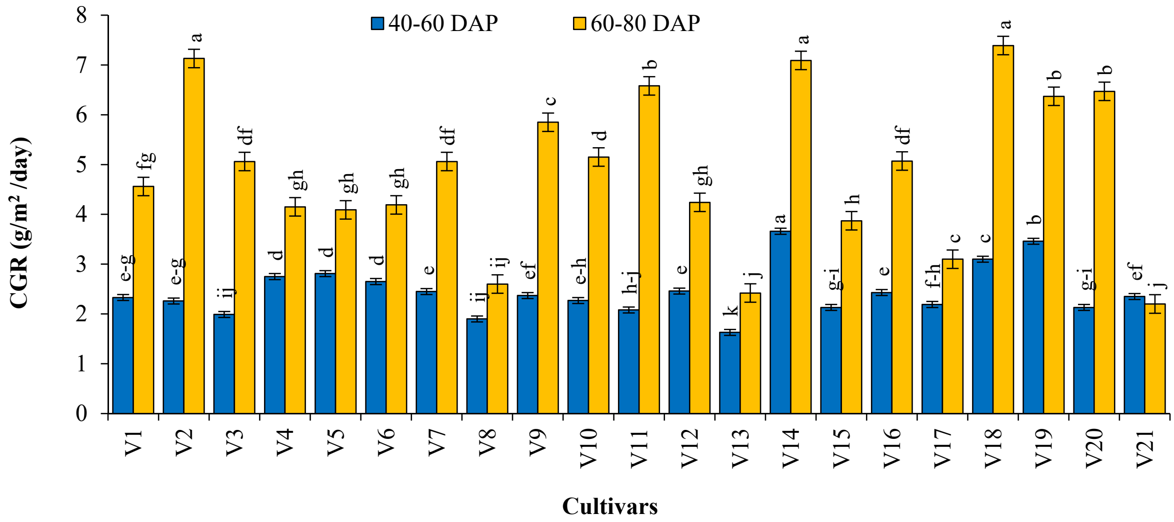

Figure 4. The crop growth rate of different potato cultivars during various stages of growth (two years pooled data); values with different lower case letters are significantly different between each other at the 5% level of significance ($p \leq 0.05$); vertical bars represent standard error of mean values.

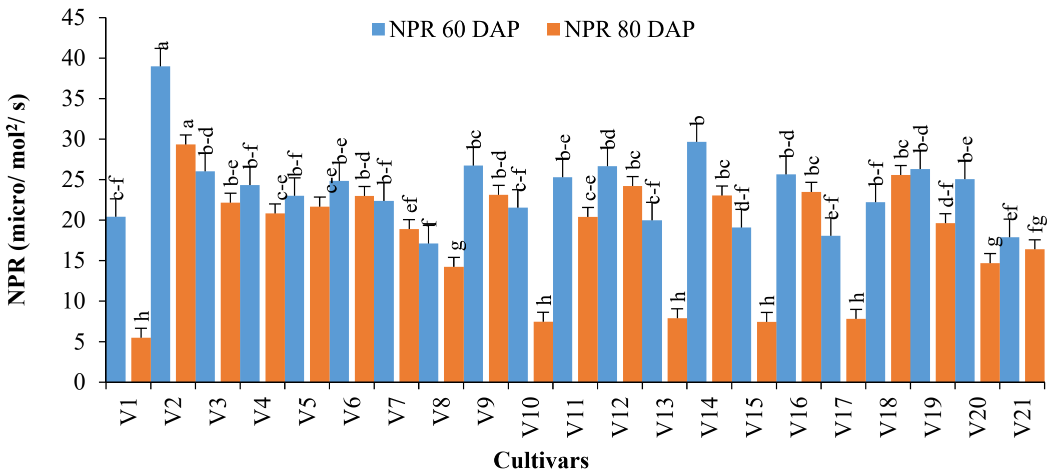

Figure 5. NPR of different potato cultivars at 60 and 80 days after planting (estimation from two years pooled data); values with different lower case letters are significantly different between each other at the 5% level of significance ($p \leq 0.05$); vertical bars represent standard error of mean values.

The cultivar 'Kufri Pukhraj' (V_2) had a higher rate of net photosynthesis as compared to other tested cultivars. The observed genotype differences in relation to rates of photosynthesis could be the major factor explaining the variation in growth rate and total biomass production.This may be due to the higher stomatal conductance in the heat-tolerant variety 'Kufri Surya' (V_{16}), which had higher transpiration and faster evaporative cooling, resulting in a higher rate of photosynthesis and better plant growth. The variation in the net photosynthetic rate at different stages of growth with different cultivars might be explained by the better growth with higher leaf area index (LAI) of the cultivars, and the greater utilization of solar radiation, resulting in an increase in the net photosynthesis rate. Good early vegetative growth carries plants more quickly to the reproductive phase, and provides sufficient photosynthates for the developing tuber.

There was a significant variation in the transpiration rate of potato among the tested cultivars (Figure 6). Among the early maturing cultivars, 'Kufri Pukhraj' (V_6) had the highest transpiration rates at 60 and 80 DAP. Among the medium maturing cultivars, 'Kufri Himalini' (V_{12}) and 'Kufri Megha' (V_{11}) had the highest transpiration rates at 60 and 80 DAP, respectively, followed by 'Kufri Surya' (V_{16}). Among the processing-type cultivars, 'Kufri Chipsona-3' (V_{18}) had the highest transpiration rate, followed by 'Kufri Frysona' (V_{20}), at 60 DAP, whereas 'Kufri Himsona' (V_{21}) had the highest transpiration rate, followed by 'Kufri Chipsona-3' (V_{18}), at 80 DAP, being on a par with each other. The reason for cultivars exhibiting a higher rate of transpiration might the variation in abscisic acid accumulation in the leaves at the corresponding growth stages. Similar results were also found by Hammes et al. [32]. This was related to the growth habit of the cultivars, the net photosynthesis rate, as well as the higher leaf surface area for the maximum production of dry matter in the potato crop. This indicates that a small leaf area initially gives the advantage of having less leaf surface exposed to intense solar radiation, such that the photorespiration and water loss from the leaf tissues are minimized, but large leaf surface areas trap more intense solar radiation, so their photorespiration is also high, with a higher transpiration rate. In this context, the cultivar 'Kufri Arun' (V_{14}) with a larger leaf size had a higher transpiration rate over the other cultivars. A high transpiration rate under conditions of water deficit also implies high stomatal conductance, which was associated with continued water extraction [33,34].

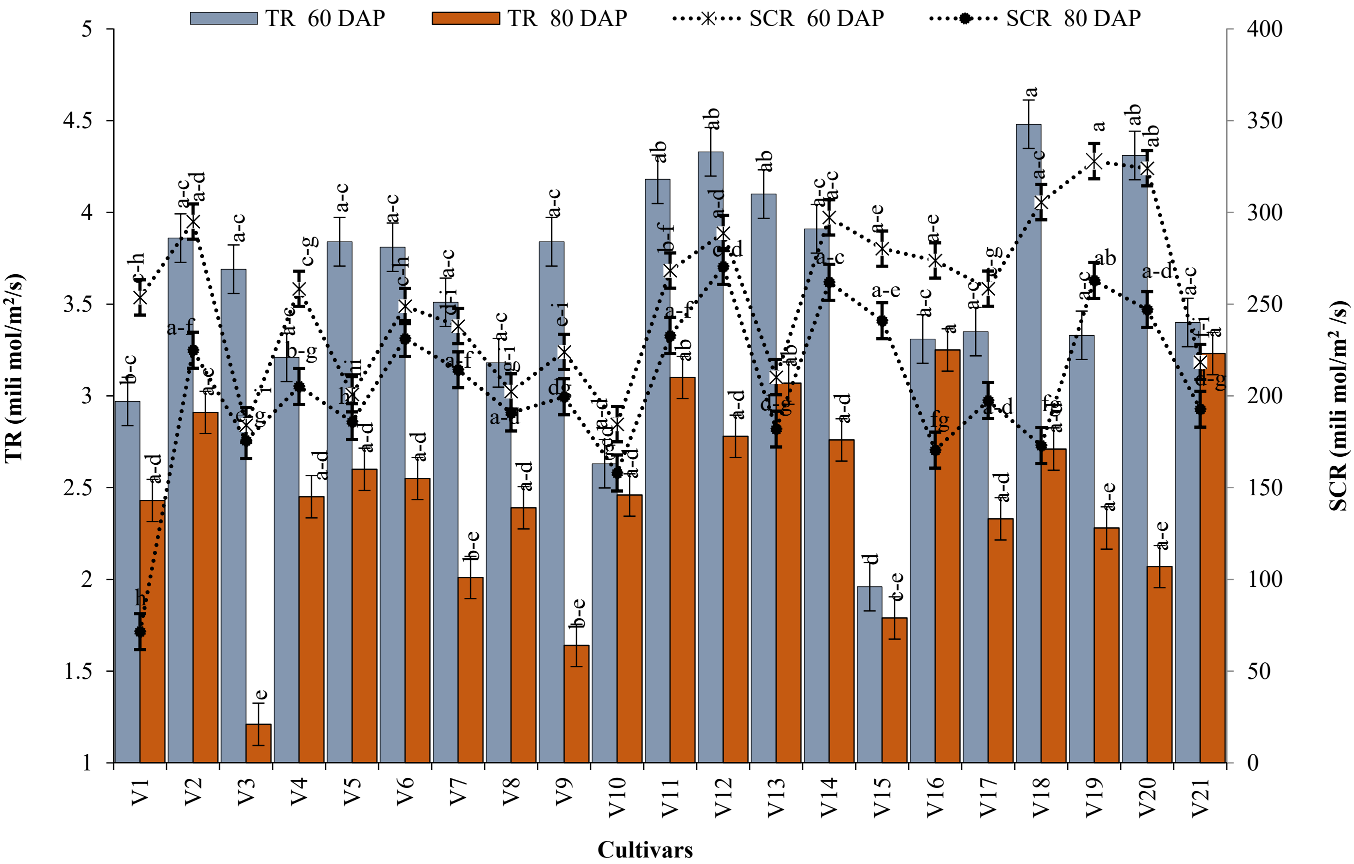

Figure 6. TR and SCR of different potato cultivars at 60 and 80 days after planting (estimation from two years pooled data); values with different lower case letters are significantly different between each other at the 5% level of significance ($p \leq 0.05$); vertical bars represent standard error of mean values.

Among the early maturing cultivars, 'Kufri Pukhraj' (V_2) had the maximum stomatal conductance rate at 60 and 80 DAP (Figure 6). Among the medium duration cultivars, 'Kufri Arun' (V_{14}) had the maximum stomatal conductance rate at 60 DAP, followed by

'Kufri Surya' (V_{16}), whereas, 'Kufri Himalini' (V_{12}) had the highest stomatal conductance rate at 80 DAP, being on a par with 'Kufri Arun' (V_{14}). However, among the processing-type cultivars, 'Kufri Chipsona-4' (V_{19}) had the maximum stomatal conductance rate, followed by 'Kufri Frysona' (V_{20}), at both 60 and 80 DAP. A similar result was found by Dwelle et al. [31], who reported the existence of genotype differences regarding stomatal diffusive resistance and stomatal conductance in potato. Actually, the stomatal conductance rate increased with the increase in LAI, and it was correlated with net photosynthesis rate at different stages of growth, and processing-type cultivars had a greater stomatal conductance rate as compared to early and medium maturing cultivars. There was variation in the stomatal conductance among the cultivars, which might be due to genetic variation [35,36]. This was supposed to be the key factor affecting transpiration rate, and its degree of influence on transpiration rate was different at different growth stages.

3.3. Tuber Bulking Rate (TBR)

The cultivars 'Kufri Pukhraj' (V_2) and 'Kufri Himsona' (V_{21}) had the maximum and minimum TBR between 41 to 60 DAP, respectively. At 61–80 DAP, the cultivar 'Kufri Arun' (V_{14}) had a significantly higher TBR, followed by 'HPS 7/67' (V_7) and 'Kufri Jyoti' (V_9), whereas 'Kufri Kanchan' (V_{10}) had the lowest TBR. However, between 81 and 90 DAP, the genotype 'Kufri Surya' (V_{16}) showed the highest TBR, followed by 'Kufri Arun' (V_{14}) and 'Kufri Himalini' (V_{12}), and the lowest was observed in 'HPS 7/67' (V_7) (Table 1). Among the early maturing cultivars, 'Kufri Pukhraj' (V_2) had the highest TBR ranging between 41 and 60 DAP, while 'HPS 7/67' (V_7) had the highest TBR between 61 and 80 DAP. Among the medium maturing cultivars, 'Kufri Kanchan' (V_{10}) had the highest TBR between 41 and 60 DAP, whereas 'Kufri Arun' (V_{14}) and the heat-tolerant variety 'Kufri Surya '(V_{16}) showed the highest TBR between 61 and 80 and 81 and 90 DAP, respectively. Among the processing-type cultivars, 'Kufri Chipsona-3' (V_{18}) had the highest TBR between 41 and 60 and 61 and 80 DAP, while 'Kufri Frysona' (V_{20}) had the maximum TBR between 81 and 90 DAP. The tuber growth phase following tuber initiation was based on the duration of the cultivar or the length of the growing season. Thus, tuber growth may continue and last from 60 to over 90 days, depending on the cultivar, and it may continue until photosynthates translocate from the shoot to the tubers. With declined leaf area and slow TBR, the crop turned to the maturation phase. This phase may not occur in the field when a medium- or long-season cultivar is grown in a short production season [37]. Only approximately 10–15% of the total tuber weight can be obtained between the end of the tuber growth stage and the first two weeks of maturation. Our findings corroborated the finding of Mihovilovich et al. [37]. Tuber bulking rate increased with increasing values of leaf area index, and TBR decreased when there was senescence of leaves, reflected through lower LAI values.

3.4. Yield Stability of Potato Cultivars

The AVOVA for the AMMI analysis of potato yield revealed that the genotypes differed significantly, but the environment and G $\times$ E interaction components did not differ significantly (Table 2). This could possibly be due to the more narrow environmental factors (only two years, i.e., 2016–2017 and 2017–2018). However, the statistical parameters, namely AMMI stability value (ASV) and yield stability index (YSI), give some idea of the stability of the potato genotypes under the present study (Table 3).

Table 2. AMMI ANOVA for potato yield (two years pooled data) over two environments.

Sources of Variation	Df	Sum Sq	Mean Sq	F value	Prob. (>F)
Environment	1	60.2	60.21	4.8483	0.09246
Replication (environment)	4	49.7	12.419	1.0782	0.3729
Genotype	20	4460.1	223.006	19.3621	$<2 \times 10^{-16}$ ***
Environment × genotype	20	122.4	6.122	0.5316	0.94439
IPCA1	20	1412.9	70.6	6.13	0
IPCA2	18	39	2.2	0.19	0.9999
Residuals	80	921.4	11.518		

***, significant at 1% level of probability.

Table 3. Potato yield (two years pooled data) stability analysis over two environments.

Sl. No.	Cultivars	Yield (t/ha)	Rank	IPCA1	IPCA2	ASV	Rank	YSI	Rank
1	Kufri Chandramukhi	17.41	17	−1.991	0.206	72.15	20	37	15
2	Kufri Pukhraj	33.54	2	1.794	−0.617	65.01	18	20	8
3	Kufri Ashoka	24.54	10	−0.238	−0.073	8.64	2	12	2
4	Kufri Khyati	27.04	7	0.385	0.169	13.93	3	10	1
5	HPS I/67	22.02	13	−0.712	−0.440	25.81	6	19	7
6	HPS II/67	23.95	11	−0.222	−0.077	8.06	1	12	2
7	HPS 7/67	26.68	8	0.461	−0.082	16.69	5	13	3
8	Pimpernel	18.60	15	−1.348	−0.590	48.83	14	29	12
9	Kufri Jyoti	29.09	5	1.115	0.169	40.41	10	15	4
10	Kufri Kanchan	18.42	16	−1.295	0.035	46.92	12	28	11
11	Kufri Megha	28.43	6	1.066	0.048	38.61	9	15	4
12	Kufri Himalini	30.16	4	1.506	0.798	54.57	16	20	8
13	Kufri Girdhari	17.03	20	−1.468	0.376	53.20	15	35	14
14	Kufri Arun	35.52	1	2.856	0.116	103.46	21	22	10
15	Kufri Giriraj	17.11	19	−1.336	−0.412	48.40	13	32	13
16	Kufri Surya	30.66	3	1.830	0.457	66.29	19	22	10
17	Kufri Chipsona-1	17.33	18	−1.171	−1.110	42.45	11	29	12
18	Kufri Chipsona-3	25.85	9	0.838	−0.564	30.35	8	17	6
19	Kufri Chipsona-4	18.93	14	−0.726	0.696	26.31	7	21	9
20	Kufri Frysona	23.57	12	0.413	−0.446	14.96	4	16	5
21	Kufri Himsona	14.08	21	−1.753	1.341	63.53	17	38	16

ASV = AMMI stability value, YSI = yield stability index.

The ranking of the ASV values reflected that the genotype 'HPS II/67' (V_6) was the most stable, due to its ASV ranking of 1 and its having the lowest ASV value (8.06). This was closely followed by the other genotypes 'Kufri Ashoka' (V_3), with rank 2 (ASV value of 8.64), and 'Kufri Khyati' with rank 3 (ASV value of 13.93). It is apparent from the present study that ASV only caters to the stability of the genotypes for yield, but does not give an indication for the high-yielding ones. The robust statistical parameter YSI, which is inclusive of both stability and superior yield, shows that the genotype 'Kufri Khyati'(V_4) is the most stable, with a substantially high yield (27.04 t ha^{-1}), due to its ranking number 1, and its having the lowest YSI value (10). Some other genotypes also showed high stability and superior yield performance, such as 'Kufri Ashoka' (V_3) with rank 2 (YSI value of 12), genotype 'HPS 7/67' (V_7) with rank 3 (YSI value of 13), and 'Kufri Megha' (V_{11}), with rank 4 (YSI value of 15). Based on ASV and YSI, the superior yielding and stable genotypes over the two years have been identified, and were found to be similar.

3.5. Tuber Yield and Economics of Production

There was a significant variation in tuber yield achieved for various potato cultivars (Table 4). Among all the cultivars taken in the experiment, 'Kufri Arun' (V_{14}) had the maximum tuber yield, followed by 'Kufri Pukhraj'(V_2), and the lowest tuber yield was observed in 'Kufri Himsona' (V_{21}). 'Kufri Pukhraj' (V_2), 'Kufri Arun' (V_{14}) and 'Kufri Chipsona-3' (V_{18}) had the significantly highest tuber yield among the early, medium maturing and processing-type cultivars, respectively. The higher tuber yield of the cultivars evaluated in this experiment might be attributed to the combined effects of the growth and yield attributes. Correlation studies were performed between tuber yield and a number of morphological and physiological parameters (Table 5). The study was suggestive of a strong positive correlation between yields and physiological parameters NPR (r = 0.802) and TBR (r = 0.782). The correlation between tuber yield and shoot DM was also significant at the p = 0.01 level. Though SCR was not significantly correlated with tuber yield, it showed a significant positive correlation between LAI and NPR.

Table 4. Yield and production economics of various potato cultivars (estimation from two years' pooled data).

Cultivars	Tuber Yield (t ha^{-1})	Marketable Yield (%) (>40 g)	Grade-Wise Tuber Yield (%)					Net Return (USD/ha)	B:C
			(<40 g)	(41–60 g)	(61–80 g)	(81–100 g)	(>100 g)		
Kufri Chandramukhi	17.41 ij	86.26	13.74	21.15	20.92	29.00	15.16	118.5	1.07
Kufri Pukhraj	33.54 ab	92.35	7.65	13.58	22.82	20.22	35.72	1911.2	2.05
Kufri Ashoka	24.54 e-g	85.23	14.7	14.92	21.93	27.87	20.50	912.0	1.50
Kufri Khyati	27.04 c-f	84.25	15.75	18.02	21.61	20.81	23.80	1191.7	1.65
HPS I/67	22.02 gh	87.47	12.53	23.52	16.90	21.13	25.91	628.5	1.35
HPS II/67	23.95 fg	85.54	14.45	13.69	17.45	18.86	35.53	845.6	1.47
HPS 7/67	26.68 c-f	83.55	16.45	15.64	22.31	24.53	21.06	1150.6	1.63
Pimpernel	18.60 hi	82.98	17.28	14.20	25.36	26.72	16.68	537.8	1.30
Kufri Jyoti	29.09 cd	86.43	13.57	16.14	19.97	20.16	30.15	1421.0	1.78
Kufri Kanchan	18.42 h-j	77.24	22.76	18.26	27.21	13.33	18.43	229.9	1.13
Kufri Megha	28.43 c-e	90.58	9.42	10.39	21.00	25.72	33.45	1345.8	1.74
Kufri Himalini	30.16 b-d	90.50	9.50	16.23	23.31	19.28	31.67	1544.3	1.84
Kufri Girdhari	17.03 ij	81.08	18.91	17.34	17.60	17.64	28.50	76.8	1.04
Kufri Arun	35.52 a	92.00	8.00	6.46	16.49	23.81	45.22	2137.4	2.17
Kufri Giriraj	17.11 ij	85.79	14.20	14.51	25.45	22.61	23.22	80.3	1.05
Kufri Surya	30.66 bc	89.10	10.90	15.65	24.41	17.62	31.41	1596.9	1.88
Kufri Chipsona-1	17.33 ij	74.18	25.82	14.14	22.48	21.92	15.62	638.3	1.36
Kufri Chipsona-3	25.85 d-g	89.04	10.45	12.69	18.03	30.78	27.53	2011.6	2.11
Kufri Chipsona-4	18.93 hi	84.13	15.86	17.05	21.59	24.76	20.72	969.4	1.53
Kufri Frysona	23.57 fg	87.70	12.3	15.34	25.72	27.72	18.92	1671.0	1.92
Kufri Himsona	14.08 j	67.53	32.47	21.34	23.58	13.11	9.49	164.9	1.08

Numbers followed by different lower case letters in a column are significantly different between each other at the 5% level of significance ($p \leq 0.05$), and are otherwise statistically on a par.

Table 5. Correlation studies between tuber yields and various morphological and physiological parameters.

Characters	Shoot DM (60 DAP)	LAI (60 DAP)	NPR (60 DAP)	SCR (60 DAP)	TBR (60–80 DAP)
Yield	0.690 **	0.583 **	0.802 **	0.372	0.782 **
Shoot DM (60 DAP)		0.912 **	0.713 **	0.617 **	0.457 *
LAI (60DAP)			0.585 **	0.716 **	0.365
NPR (60DAP)				0.415	0.427
SCR (60DAP)					0.193

** Correlation is significant at the 0.01 level (2-tailed); * correlation is significant at the 0.05 level (2-tailed).

In general, the higher yields were mainly attributed to the higher number of tubers per plant and the higher tuber yields per plant [38]. The comparatively lower yields of the varieties 'Pimpernel' (V_8) (among the early cultivars) 'Kufri Kanchan' (V_{10}), 'Kufri Girdhari' (V_{13}), 'Kufri Giriraj' (V_{15}) (among the medium), and 'Kufri Chipsona-1' (V_{17}), 'Kufri Chipsona-4' (V_{19}) and 'Kufri Himsona' (V_{21}) (among the processing-type) might be due to the low adaptation of this variety to this region of eastern Sub-Himalayan plains. Various reports have confirmed this variation in the total tuber yield of different genotypes/varieties under different locations and climatic conditions [39–42]. It was revealed from the result that tuber yield was absolutely related to TBR, and the cultivars with high TBR reflected higher yields. There was wide variation in the marketable yield percentage, and it was revealed that among all the cultivars, 'Kufri Pukhraj' (V_2) had the maximum marketable yield.

The cultivars varied greatly according to grades (according to the weight of the individual tuber). Among the early mature cultivars, Pimpernel reflected the highest (61–80 g)-grade tubers, while 'Kufri Ashoka' (V_3) had the highest (<40 and 81–100 g)-grade and 'HPS I/67' (V_5), and 'Kufri Pukhraj' (V_2) produced higher percentages of 41–60 g and >100 g tubers. In terms of medium maturing cultivars, 'Kufri Kanchan' (V_{10}) had higher percentages of 41–60 and 61–80 g tubers, while 'Kufri Girdhari' (V_{13}), 'Kufri Megha' (V_{11}) and 'Kufri Arun' (V_{14}) had a higher percentage of <40, 81–100 and >100 g tubers, respectively. Kumar et al. [43] reported significant varietal variations in marketable and total tuber yield under the conditions of Modipuram, India. The variation in the marketable yield of potato cultivars may be due to genotypic/varietal factors. Similar results for the variation in marketable yield among cultivars were reported by Khan et al. [40], Kumar et al. [41] and Luitel et al. [44]. Actually, chip-grade tubers (>40 g size) obtained from 'Kufri Chipsona-3' (V_6) (76.36%) and 'Kufri Frysona' (V_{20}) (72.37%) showed superiority over other processing-type cultivars, and the farmers may obtain more economic benefits from these processing-type cultivars depending upon the purpose. It was reflected in the study that the processing varieties performed well in the eastern Sub-Himalayan Bengal plains of India. In terms of production economics, 'Kufri Arun' (V_{14}) achieved the maximum net return (USD 2137.4) and B: C ratio (2.17), suggesting the suitability of this cultivar in the eastern Sub-Himalayan plains of West Bengal, India. However, among the early maturing cultivars, 'Kufri Pukhraj' (V_2) recorded the highest net return (USD 1911.2) and B:C ratio (2.05), while 'Kufri Chipsona-3' (V_{18}) (net return of USD 2011.6 with a B:C ratio of 2.11) showed its superiority among the processing-type cultivars.

4. Conclusions

From this two-year study, it can be concluded that 'Kufri Arun' performed best in terms of productivity and profitability amongst all the 21 cultivars taken in the experiment. However, there remains a good scope for popularizing the processing-type cultivars in the eastern Sub-Himalayan plains of West Bengal, India. Under the circumstances, 'Kufri Chipsona-3' would be the choice, considering its productivity and profitability. Te heat-tolerant variety 'Kufri Surya' achieved good yields and economic returns, suggesting the suitability of the cultivar in this region under terminal heat stress. However, the ranking of the ASV values reflected that the genotype HPS II/67 was the most stable due to its ASV ranking of 1 and lowest ASV value (8.06). The robust statistical parameter YSI, which is inclusive of both stability and superior yield, shows that the genotype 'Kufri Khyati' is the most stable, with a substantially higher yield performance.

Author Contributions: Conceptualization, S.D., B.M. and A.S.; methodology, S.D. and B.M.; software, S.D.; B.M.; S.K.L., A.H. and A.S.; validation, S.D., A.S. and B.M.; formal analysis, S.D., B.M.; A.H. and S.K.L.; investigation, S.D.; B.M.; resources, B.M. and A.H.; data curation, S.D., B.M., A.H. and S.K.L.; writing—original draft preparation, S.D., B.M., A.H. and S.K.L. and A.S.; writing—review and editing, A.H. and M.M.H.; supervision, A.S. and B.M.; project administration, B.M.; funding acquisition, A.H. and M.M.H. All authors have read and agreed to the published version of the manuscript.

Funding: The current work was funded by Uttar Bangla Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal, India and also Taif University Researchers Supporting Project number (TURSP–2020/59), Taif University, Taif, Saudi Arabia.

Data Availability Statement: Data may be available after request.

Acknowledgments: The authors would like to thank Hon'ble Director of Research, Uttar Bangla Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal, India for providing resources to complete the trials. The authors also extend their appreciation to Taif University for funding the current work by Taif University Researchers Supporting Project number (TURSP–2020/59), Taif University, Taif, Saudi Arabia.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Devaux, A.; Kromann, P.; Ortiz, O. Potatoes for sustainable global food security. *Potato Res.* **2014**, *57*, 185–199. [CrossRef]
2. Luthra, S.K.; Gupta, V.K.; Tiwari, J.K.; Kumar, V.; Bhardwaj, V.; Sood, S.; Dalamu, D.; Kaur, R.P.; Kumar, R.; Vanishree, G.; et al. *Potato Breeding in India*; CPRI Technical Bulletin No 74 (revised); ICAR-Central Potato Research Institute: Shimla, India, 2020; 214p.
3. Mohammadi, J.; Khasmakhi-sabet, S.A.; Olfati, J.A.; Dadashpour, A.; Lamei, J.; Salehi, B. Comparative studies of some new potato cultivars and their morphological characteristics. *Biosci. Biotech. Res. Asia* **2010**, *7*, 121–126.
4. Haldavankar, P.C.; Joshi, G.D.; Bhave, S.G.; Klandekar, R.G.; Sawant, S.S. Stability of yield and yield attributing phenotypic characters in sweet potato. *J. Root Crops.* **2009**, *35*, 28–35.
5. Mkumbira, J.; Mahungu, N.M.; Gullberg, U. Grouping locations for efficient cassava evaluation in Malawi. *Exp. Agric.* **2003**, *39*, 167–179. [CrossRef]
6. Aina, O.O.; Dixon, A.G.O.; Paul, I.; Akinrinde, E.A. G × E interaction effects on yield and yield components of cassava (landraces and improved) genotypes in the savanna regions of Nigeria. *Afr. J. Biotechnol.* **2009**, *8*, 4933–4945.
7. Falconer, D.S.; Mackay, T.F.C. *Introduction to Quantitative Genetics*; Longman: New York, NY, USA, 1986.
8. Gauch, H.G. Model selection and validation for yield trials with interaction. *Biometrics* **1988**, *44*, 705–715. [CrossRef]
9. Van Eeuwijk, F.A. Linear and bilinearmodels for the analysis of multi-environment trials: I. An inventory of models. *Euphytica* **1995**, *84*, 1–7. [CrossRef]
10. Kumar, V.; Luthra, S.K.; Bhardwaj, V.; Singh, B.P. *Indian Potato Varieties and Their Salient Features*; Technical Bulletin No. 78 (revised); ICAR-Central Potato Research Institute: Shimla, India, 2014.
11. Rajesh, K.R. The Indian potato processing industry Global comparison and business prospects. *Outlook Agric.* **2011**, *40*, 237–243.
12. Saxena, R.; Mathur, P. Analysis of potato production performance and yield variability in India. *Potato J.* **2013**, *40*, 38–44.
13. Ghulam, A.; Hafiz, I.A.; Abbasi, N.A.; Hussain, A. Determination of processing and nutritional quality attributes of potato genotypes in Pakistan. *Pak. J. Bot.* **2012**, *44*, 201–208.
14. Patil, U.V.; Sushendra, S.; Kawar, P.G.; Bardwaj, V.; Singh, B.P.; Nagesh, M. *Biology of Solanumtuberosum (Potato) Phase II Capacity Building Project on Biosafety*; Series of Crop Specific Bilogy Document; Ministry of Environment, Forest and Climate Change (MoEF&CC) GOI: New Delhi, India, 2014; pp. 1–39.
15. Rana, L.; Banerjee, H.; Dutta, S.K.; Ray, K.; Majumdar, K.; Sarkar, S. Management practices of macronutrients for potato for smallholder farming system at alluvial soil (Entisols) of India. *Arch. Agron. Soil Sci.* **2017**, *63*, 1963–1976. [CrossRef]
16. Panse, V.G.; Sukhatme, P.V. *Statistical Methods for Agricultural Workers*; Indian Council of Agricultural Research Publication: New Delhi, India, 1985; pp. 87–89.
17. Purchase, J.L.; Hatting, H.; van Denventer, C.S. Genotype × environment interaction of winter wheat (*Triticum aestivum* L.) in South Africa: II. Stability analysis of yield performance. *S. Afr. J. Plant Soil.* **2000**, *17*, 101–107. [CrossRef]
18. Mohammadi, R.; Abdulahi, A.; Haghparast, R.; Armion, M. Interpreting genotype-environment interactions for durum wheat grain yields using non-parametric methods. *Euphytica* **2007**, *157*, 239–251. [CrossRef]
19. Mohammadi, R.; Amri, A. Comparison of parametric and non-parametric methods for selecting stable and adapted durum wheat genotypes in variable environments. *Euphytica* **2008**, *159*, 419–432. [CrossRef]
20. Rao, A.R.; Prabhakaran, V.T. Use of AMMI in simultaneous selection of genotypes for yield and stability. *J. Indian Soc. Agric. Stat.* **2005**, *59*, 76–82.
21. Babarmanzoor, A.; Tariq, M.S.; Ghulam, A.; Muhammad, A. Genotype × environment interaction for seed yield in Kabuli Chickpea (Cicer arietinum L.) genotypes developed through mutation breeding. *Pak. J. Bot.* **2009**, *41*, 1883–1890.
22. Knowles, N.; Knowles, L. Manipulating stem number, tuber set, and yield relationships for northern and southern-grown potato seed lots. *Crop Sci.* **2006**, *46*. [CrossRef]
23. Singh, R.K.; Singh, J.P.; Lal, S.S. Dry matter partitioning relative to development in high yielding Indian potato cultivars under short day tropical conditions. *Potato J.* **2008**, *35*, 161–166.
24. Chakraborty, H.; Arora, R.P. Spectral reflectance of rice under different irrigation and nutrient management. *Ann. Agric. Res.* **2003**, *24*, 492–497.
25. Weraduwage, S.M.; Chen, J.; Anozie, F.C.; Morales, A.; Weise, S.E.; Sharkey, T.D. The relationship between leaf area growth and biomass accumulation in Arabidopsis thaliana. *Front. Plant Sci.* **2015**, *6*, 167. [CrossRef] [PubMed]
26. Machado, D.; Sarmiento, L. Raspiest del cultivar de papa a la combination de differences Fuentes de fertilization nitrogenada: Evaluando la hipótesis de la synchronization. *Bioagro* **2012**, *24*, 83–92.
27. Gastal, F.; Lemaire, G. N uptake and distribution in crops: An agronomical and Eco-physiological perspective. *J. Exp. Bot.* **2002**, *53*, 789–799. [CrossRef]
28. Takai, T.; Matsuura, S.; Nishio, T.; Ohsumi, A.; Shiraiwa, T.; Horie, T. Rice yield potential is closely related to crop growth rate during late reproductive period. *Field Crops Res.* **2006**, *96*, 328–333. [CrossRef]

29. Wang, H.Q. Correlation between nitrogen application rate and the growth and development of hybrid rice. *Fujian J. Agric. Sci.* **2007**, *22*, 245–250.
30. Feng, D.Y.; Qiu, X.F.; Yan, J.Y.; Wang, C.L. Simulation of net photosynthetic rate of rice; Department of Applied Meteorology, Nanjing Institute of Meteorology, Nanjing, Jiangsu 210044, China. *J. Nanjing Ins. Meteor.* **1995**, *18*, 269–275.
31. Dwelle, R.B. *Photosynthesis and Photosynthate Partitioning*; Li, P.H., Ed.; Potato Physiology Academic Press Inc.: Orlando, FL, USA, 1985; pp. 35–58.
32. Hammes, P.S.; Wondimu, B.; Rethman, N.F.G.; Pieterse, P.A.; Grimbeek, J.; Vander, M. Water stress affects the germination, emergence and growth of different Sorghum cultivars. *Ethiop. J. Sci.* **2005**, *28*, 119–128.
33. Cabuslay, G.S.; Ito, O.; Alejar, A. Genotypic differences in physiological responses to water deficit in rice. In *Genetic Improvement of Rice for Water Limited Environments*; International Rice Research Institute: Los Banos, Philippines, 1999; pp. 99–116.
34. Kamoshita, A.; Wade, L.J.; Yamanchi, A. Genotypic variation in response of rainfed lowland rice to drought and rewatering III. Water extraction during drought period. *Plant Prod. Sci.* **2000**, *31*, 189–196. [CrossRef]
35. Price, A.H.; Young, E.M.; Tomos, A.D. Quantitative trait loci associated with stomatal conductance, leaf rolling and heading date mapped in upland rice (*Oryza sativa* L.). *New Phytol.* **1997**, *137*, 83–91. [CrossRef]
36. Hoque, M.M.; Kobata, T. Growth responses of drought resistant rice cultivars to soil compaction under irrigated and succeeding non irrigated conditions during the vegetative stage. *Plant Prod. Sci.* **1998**, *1*, 183–190. [CrossRef]
37. Mihovilovich, E.; Carli, C.; De Mendiburu, F.; Hualla, V.; Bonierbale, M. *Tuber Bulking Maturity Assessment of Elite and Advanced Potato Clones Protocol*; International Potato Center: Lima, Peru, 2014; 43p. [CrossRef]
38. Joseph, T.A.; Singh, B.P.; Kaushik, S.K.; Bhardawaj, V.; Pandey, S.K.; Singh, S.V.; Gopal, J.; Singh, P.H.; Gupta, V.K.K. Himalini: A high yielding, late blight resistant potato variety suitable for cultivation in Indian hills. *Potato J.* **2007**, *34*, 153–158.
39. Sharma, Y.K.; Thakur, K.C.; Bhutani, R.D.; Trivedi, S.K.; Singh, B.P.; Verma, R.B. On-farm evaluation of promising potato genotypes for adaptability in northern plains and plateau regions of India. *Potato J.* **2005**, *32*, 238.
40. Patel, R.N.; Patel, N.H.; Singh, S.V.; Pandey, S.K.; Patel, J.M.; Patel, S.B. Assessment of potato varieties/hybrids for French fries and storage behavior in Gujarat. *Potato J.* **2005**, *32*, 217–218.
41. BhuwneshwariVerma, S.K.; Narayan, K.; Paikra, M.S. Evaluation of processing potato genotypes for growth, yield and yield attributes under Chhattisgarh condition. *Asian J. Hort.* **2013**, *8*, 241–245.
42. Khan, M.F.; Tabassum, N.; Latif, A.; Khaliq, A.; Malik, M. Morphological characterization of potato (*Solanum tuberosum* L.) germplasm under rainfed environment. *Afr. J. Biotech.* **2013**, *12*, 3214–3223.
43. Kumar, S.; Kumar, D.; Minhas, J.S. Varietal differences in response of potatoes to repeated periods of water stress in winter crop. *Potato J.* **2005**, *32*, 197–198.
44. Luitel, B.P.; Khatri, B.B.; Choudhary, D.; Paudel, B.P.; Jung, S.S.; On-Sook, H. Growth and yield characters of potato genotypes grown in drought and irrigated conditions of Nepal. *Int. J. Appl. Sci. Biotech.* **2015**, *3*, 513–519. [CrossRef]