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Chapter

Perspective Chapter: Physiological Breeding Approach for Sustainable Smart Farming

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Abstract

Smart farming is referred as managing farm efficiently using information and communication techniques to increase the quantity and quality of the product. The basic and fundamental concept of smart farming in agriculture is to exploit yield determinants efficiently so as to attain genotype x environment interaction zero by introgression of trait of interest demanded by the environments. Accordingly, the physiological breeding approach coupled with mega environment concept could be a sustainable smart farming, which could be exploited to fulfill the future food demand. This chapter is conceptualized with scientific information available on potato under India such as low land tropic scenario.

Keywords: trait driven breeding, mega-environment, yield determinants, sustainable smart farming, physiological breeding

1. Introduction

The projection shows that feeding the world population of 9.1 billion by 2050 would require raising overall food production by 70%. Considering the future food demand, the trait-driven breeding approach is essential to exploit natural resources to obtain high yield/quality potential of a region in smart manner. The currently developed varieties under conventional approaches seldom express its high genetic potential in every mega environments due to lack of identification of mega environments and its demanding trait of interest for improved yield. Presently, the improved varieties are developed in an environment and tested them at across the environments and selected the best-performed locations for recommendation. Due to which, testing of varieties developed at across locations frequently exhibits low to moderate yield potential as it lacks the specific traits of interest for high potential. Hence, physiological/ideotype breeding for mega environments could result with high potential varieties. Thus, this chapter deals about potato as test crop, present growing scenario and future strategies for yield enhancement considering trait-driven breeding approach for mega-environments concept.

Potato is the fourth most important food crop in the world and is also the most consumed food crop grown in >125 countries. It is top ranked food crop, which
supplies 80% edible dry matter. According to Statistics, 52% of crop area lies in the temperate region (Europe), 34% in Asia, and 14% in Africa. Asian and African countries had low productivity as against Europe where it is quite high. However, the estimated potential yield of potato ranged between 40 and 140 t/ha under optimal growing environments [1] depending upon the length of growing season and temperature. India is the second largest producer of potato in the world by producing 53.11 million tons from 12.247 million hectares during 2020–2021. This has been possible due to the adaptation of the crop to different agro ecological conditions in India. Due to which, it has now been spread from hills and plateau (>800 M msl) to the plains (<300 M msl.). The plains presently account for more than 80% of the Indian potato acreage (Figure 1), and the hills and plateaus account about 15%. Under plains, about 90% of total production is restricted in subtropical plains, mainly Indo-Gangetic belt (76%), 6% in the hills, and about 4% in plateau region of peninsular India.

Considering the future potato demand of the world, Bradshaw [2] clearly predicted that the leading production primarily happened not only through area expansion in potato, but also accompanied by increased productivity. These trends cannot be continued as such, as the demand gap should be primarily reduced through by increase in productivity as new land will not be so readily available for area expansion under potato in future. Although, India contributes significantly in terms of production, the yield potential realized among the growing zone was very wider due to ecological diversity. An encouraging finding on the similar line, the modern potatoes had high harvest index (0.80) and tuber fresh-weight yields of 120 t/ha achieved in Western Australia prevailed with a long growing season, absence of pests and pathogens with adequate inputs of water and fertilizers [3]. Although these yields are not achieved in practice presently, it supports that the long growing season (hills and plateau) would contribute significantly to meet the future demand of potato in India provided the genetic potential of genotypes is enhanced. Secondly, attaining the yield potential of temperate countries by the tropics and sub-tropics is not easily possible due to shorter growing season with lower efficiency per unit of intercepted radiation due to prevalence of high temperature in Subtropics. However, the countries with long crop season (England) had achieved yield potential from 22 t to 45 t/ha despite the area of cultivation reduced to half during the period from 1993 to 2006 (British Potato Council Statistics) due to the intervention of superior yielding varieties. Hence, the limited area having long growing season (hills and plateaus) and larger area having
short growing season (plains) should be exploited systematically using smart farming for productivity enhancement to meet the future demand of potato in India.

Physiologically, the potato productivity is influenced by environments that include the internal (genetic) and external factors (climatic, edaphic, biotic, physiographic, and also socioeconomic factors). Although, potatoes have been adapted to warm climate and grown successfully in tropics, tuber yields remain lesser [4] due to an unfavorable allocation of assimilates within the plant. Yield is the outcome of the product of incident radiation, radiation use efficiency, and harvest index.

Haverkort and Harris [5] reported that temperatures above 23°C favor allocation of dry matter to the foliage at the cost of tuber growth. The pictorial diagram given below indicates the dissecting the potato yield into different components (daily total dry matter increment, light interception, leaf area growth, and daily growth of organ vary from growth phase and thermal region of growth phase. Hence, the genotypes utilizing the available resources efficiently are better yielder. Rawat et al. [6] reported that potato relative yield index estimated across locations in India had ranged from less than 25% to more than 125% indicating wider variability (Figure 2). Harvest index is a measure of the proportion assimilates partitioned into harvested organs. Plant physiologist and breeders adapted harvest index as a selection index for breeding high-yielding cultivars; however, Gawronska et al. [7] opined that high harvest index may not necessarily correlate with high yield. A cultivar is able to produce high rate of carbon assimilates and maintain active growth later in the season, thereby giving high yield in spite of the harvest index value, which implied that in addition to climate and edaphic factors (environment), the genotype interaction for the maximum resource use efficiency is also very much essential.

2. Understanding the climate diversity

The above-ground environments (temperature, humidity, rainfall, photoperiod, and solar radiation) and below-ground environments (soil type, nutrient and moisture, pH, etc.) determine the yield potential. In order to exploit the growing environment, there is need for testing of genotypes at multilocations (MLT) in the hills, plateaus, and plains across the country to recommend the best variety to its most adapted domain. The figure of climatic normals estimated had the mean maximum temperature of growing period of 90 days ranged from 21.1°C to 32.6°C at 25 locations, where the minimum temperature was recorded between 8.0°C and 20.9°C. This diversity can be exploited to evaluate the hybrids for their performance under different stress levels. Considering the above fact, the process of photosynthesis is very sensitive to high temperature where the optimum temperature for photosynthesis in potato is reported to be about
20°C, and at an increment of 5°C above, the optimum is expected to decrease photosynthetic rate by 25% [8]. The optimum canopy net photosynthetic rates in potato have been reported at 24°C, while the maximum biomass accumulation has been reported between 18 and 20°C [9, 10]. Accordingly, the 25 centers can be classified according to mean temperature of the growing season, where in Pantnagar, Srinagar, and Jalandhar, the mean temperature of the growing season is expected to be quite low, and hence, the growth and development of the crop would be slow, and hence, at these centers, the crop could experience low temperature stress. This is also reflected in the thermal time accumulated for 90 days <1600 at these centers. The optimum temperatures of 18–20°C would be prevalent in Kanpur, Shillong, Shimla, Patna, Hissar, Dholi, Chinwara, Kota, and Modipuram. Hence, these centers are ideal for evaluating genotypes for their yield potential under optimal temperature condition. This is also reflected in the accumulated GDD at these locations, which ranged from 1600 to 1800 degree days. Mild stress is characterized with mean temperature of 20–22°C, which prevailed in Gwalior, Kalyani, Jorhat, and Raipur, while high stress (with mean temperature > 22°C) recorded in Bhubaneshwar, Pune, Deesa, and Darwad. This finding clearly proved that these four centers are the target locations for evaluating genotypic performance against heat stress conditions. Additionally, the mean temperature of these four locations was reflected high as corresponding to high-growing degree days accumulated (>2000°Cd). A wider variability in mean night temperature of the growing season ranges from 11.3°C (Pantnagar) to 22.9°C (Dharwad). Similar variability also exists for incident solar radiation. The yielding ability of a genotype is an outcome between the reactions of the genotype interaction with different agro-ecological conditions. Knowledge on G x E is very important for choosing varieties to realize high yields and stable production [11]. Small genotypic reactions due to changed environmental condition are desirable in agricultural production [11], since the genotypes with a minimum yield variation at varied environments are considered stable [12, 13]. It has also been proven from the multilocational trials (MLTs) that the genotypes did not follow the similar trend at across the locations tested due to their interaction pressure against the environment pressure.

In physiological sense, the life cycle of potato can be divided into two stages (growth stage and tuber stage). The growth stage begins immediately after breaking the dormancy of tuber results with sprouting. However, in agronomical sense, the growth stage starts after planting of tuber in the field and continues till tuber mature. The tuber stage begins from tuber attaining maturity to subsequent its planting as seed. According to Pushkarnath [14], there is an extended time required for

![Figure 3. Growth stage specific duration differential in mid/late genotypes of potato at hills and plains.](image-url)
the same genotype of potato grown under hills for germination (10 days), vegetative (30 days), and tuberization (10 days) as compared with growing in plains (Figure 3). So, the same genotype grown under hills required 40–50 days extra period to complete its life cycle than that grown in plains. This extra period encounters with all other environment components’ pressure to result in better yield. Hence, clear dissecting of environmental components’ contribution of a location needs to be determined to extrapolate in the climate similarity areas to recommend the genotype.

3. Identification of mega environments

A huge environmental variation and varied genotypic behavior necessitated to use specialized technique for Genotype x Environment and its interactions. A common way of screening genotypic reaction to environmental factor is “multi-environment trials” (METs). In MET, a number of genotypes while evaluated at a number of geographical locations for a number years encounter different pattern of stresses, which predicts the response of genotype for future growing environments as their stress tolerance level differs from each other. In order to study a Genotype x Environment interaction, different kinds of trials are being adopted and regional yield trials with a kind of network of experiments having a set of cultivars performances assessed to make a genotype recommendations [15]. The test location within the target region should adequately represent [16], having major cropping areas and farm practices in order to reflect the variation in climate, soil, biotic, and crop management factors. The test site should not be lower than 6–7, and the trials time should be about 2–3 years to distinguish repeatable from non-repeatable GxE interaction effects.

A recent concept for identifying target domain of genotype with minimum field trials is the mega environment concept [17]. The basic principle behind mega environment concept is the interaction pattern between the genotype and environments. Griffith et al. [18] proposed four types of interaction between genotype and environments, where additive (A), divergence (B), and convergence (C) interaction showed a parallel or non-parallel relation between genotype and environment due to which one genotype (either G1 or G2) showed superior yield consistently at both environments with slight differences in its yield level. Whereas the crossing-over (D) interaction is the most useful model, where the reaction norms are non-parallel, and there is a strong Genotype x Environment Interaction (GEI), and the relative difference between the yield level of G1 and G2 varies among the environments, and the low-yielding genotype in E1 may be superior-yielding genotype in E2. Hence, a mega environment is defined as a group of locations that consistently share the same best cultivar(s) [19], and mega environment could divide the target environments into meaningful mega environments to deploy different cultivars for different mega environments for utilization of positive GEI and to avoid negative GEI [20]. Due to which, the cultivar-location interaction pattern can be repeatable across the years. Based on the adaptability of cultivar selection, the target environments are classified into three groups, such as single simple ME, multiple ME, and single complex ME, which have unique feature as given in Table 1.

In order to assess the crossing-over interaction, both AMMI and GGE biplots are the data visualization tool, which graphically displays GEI in a two-way table [17] to identify mega environment and candidate genotypes. According to Kroonenberg [21], the GGE biplot analysis is based on environment-centered PCA, while AMMI analysis is double-centered PCA where AMMI stands for the additive main effect and multiplicative interaction [22], and GGE biplot stands for genotype main effect plus GEI [23].
Hence, the GGE biplot has many visual interpretations of any crossover GEI [17]. GGE biplot technique explains the relation among the environments, discriminating ability of an environment, stability of genotypes, and comparison of genotypes with ideal genotypes. Hence, these factors explore the relationships between genotypes and environments. The genotypes with more similarity to each other are very closer to each other positioned in the same plot than genotypes are less similar. The same is true for environments too. Genotypes x Environments that are alike tend to cluster together and the angle between environmental axes is related to the correlation between the environments (Figure 4).

4. Environmental determinants of yield

Yield of edible or economical part of a plant is an ultimate goal of any improvement, which relied heavily on modifying the phenotype of crops and finding its
genetic basis for its adaptation. Hence, a very successful intervention is to modify the phenological pattern of crop so as to avoid stress [24], to minimize the occurrence of stress through the modified traits (root system) that permits accessing water from deeper in the soil during drought conditions [25], and to match the transpiration rate and evaporative demand [26]. Because, improving the genetic potential of crop for yield depends on introducing the right adaptive traits into broadly adapted, high-yielding agronomic backgrounds. Mega environment and physiological breeding would exploit the environment as well as genetic potential of a plant better than conventional breeding. The following three environment determinants influence yield, and manipulating them according to the need is the priority of the hour.

4.1 Incident solar radiation

The tissue temperature is altered by the rate of radiant energy absorbed by plants, which consequently changes the metabolic process due to energy exchange and results in transpiration. Secondly, the visible fraction of the incident solar radiation can be utilized in the synthesis of reduced carbon compounds (photosynthesis). Thirdly, the energy of specific wave lengths in the solar spectrum can be used by plants as cues for growth strategies. As an example, the red: far red ratio that can influence plant form and dry matter distribution among plant components and the diurnal duration (photoperiod) of incident solar radiation, which can influence the rate of development.

\[
PAR_{abs} = PAR_0 \left(1 - e^{-kLAI}\right)
\]

(1)

Photosynthetically active radiation incident is equal to half of the solar radiation [27].

4.2 Radiation use efficiency

Under optimum growing conditions, the biomass productivity of different species is defined by the amount of solar radiation intercepted by the green foliage and the efficiency with which such intercepted radiation is converted into plant dry matter. Hence, for most crop species, which grow in the absence of biotic and abiotic stress, the amount of dry matter produced is almost linearly related to the amount photosynthetically active radiation (PAR) intercepted by its green leaf area [28, 29]. Hence, the regression line of cumulative crop biomass versus accumulated intercepted PAR is defined as radiation-use efficiency (RUE) [30]. RUE is referred to above-ground dry matter produced per unit of intercepted PAR (gMJ\(^{-1}\)).

\[
RUE_p = \frac{TDM}{PAR_0 \cdot F_p}
\]

(2)

4.3 Harvest index

Harvest index (HI) is defined as the ratio of harvested edible produced to total shoot dry matter. In potato, cultivars grown in temperate climates with favorable agrometeorological conditions reach the high HI values (0.75–0.85), for the final crop [1, 31–33]. According to reports, it is possible to reach HI of about 90% (HI = 0.90)
biomass distribution to tubers [1]. However, the yield has almost doubled in cereal crops as the result of genetic manipulation by plant breeding, despite no change in the rate of photosynthesis per unit leaf area. Alternately, the total photosynthesis has increased as a result of an increase in leaf area, daily duration of photosynthesis, or leaf area duration. Hence, there are opportunities to alter crop duration and the time of crop development to match it to better to radiation, temperature, and vapor pressure during crop growth and to increase the rate of development of early leaf area to achieve rapid canopy closure. Hence, identification of selectable traits in a breeding program to improve crop photosynthesis is helpful to consider the components of biomass production. Assuming there is no water limitation, biomass production is the product of the solar radiation over the duration of the crop period (Q), corrected for the amount intercepted by the crop canopy (I), and the conversion of this chemical energy (E) into plant dry matter. Hence, to increase the duration of crop photosynthesis, there should be an increase in total solar radiation received.

5. Exploitation of yield determinants for greater productivity

5.1 Enhanced duration of crop photosynthesis

Considering potato under subtropical low lands, enhancing crop duration is not possible as it has very short crop duration due to short winters. Alternately, hills and plateaus have longer suitable crop duration; however, there is lack of late maturing genotypes. Extending crop duration is the simplest genetic way to increase total photosynthesis, crop biomass, and yield because longer crop duration simply increases the solar radiation interception (Q). The duration of growth that can not only be manipulated to increase biomass and yield, but also its timing should be taken care of. Full light interception should be achieved by the time daily solar radiation is at its maximum when the manipulation for crop phenology better matches to the periods of high radiation with critical growth stages. A high photo-thermal quotient is favorable since high radiation results in increased photosynthesis, whereas low temperature results in slower development during the critical period of high radiation, adjusting phenology by genetically manipulating development time so that the tuber development stage coincides with a high photo-thermal quotient. However, the period of higher solar radiation with water is a limiting factor, then maximizing growth when conditions are cool and vapor pressure deficit is low will increase water use efficiency and biomass production. This can be applicable for kharif potato genotypes development program.

5.2 Enhanced interception of solar radiation and rate of photosynthesis through leaf traits

Early growth of leaf area: In cereals, larger and bold-seeded genotypes give probably larger seedlings and thereby more vigorous and larger plants. Also, larger leafier young plants establish more quickly. In potato too, larger tuber size may influence vigorous seedling. Selection for both these traits would result in more competitive crop growth rates for which leaf dimension also should be prioritized [34]. Numerous opportunities exist to increase light interception genetically during the early development period of crops; however, lodging is the phenomenon in potato that where the solar radiation interception
is hindered. Hence, non-lodging would help more in exploiting solar radiation and higher yield needs attention in the breeding program.

Specific leaf area: SLA is the ratio of leaf area to leaf weight, and the speed of emergence is also found to be important [35]. The lodging resistance genes allow the cultivars to grow with more fertilizer under adequate rainfall or irrigation water (higher inputs) results in substantially greater crop yields. In wheat, the non-lodging genes (Rht1 and Rht2) increased the harvest index without reducing above-ground biomass, thereby resulting in greater yields. Similarly, the slower leaf area growth associated with these dwarfing genes comes about from a delay in emergence [36] and from the reduced cell size in wheat [37]. Although there is a higher SLA, a lower assimilation rate is resulted due to reduction in the amount of photosynthetic machinery per unit leaf area. Hence, the increase in leaf area compensating for the reduction in photosynthesis through greater light interception early in crop development is advocated.

Leaf Area Index: Longer the green leaf area enhances the photosynthesis duration. In Potato, the leaf area index starts declining after 40–50 days of emergence, which is the stage when sink strength would be more due to tuber formation and its development, which require more assimilation for higher yields. LAI is another important means to increase total crop photosynthesis and hence, biomass production through increased or extended light interception. Longer duration of leaf photosynthetic activity has contributed to increased yield in most of our major crops. It is difficult to separate the effects of genetics to increase photosynthetic duration due to better nutrition, genetic resistance to foliar diseases such as late blight, and differences among genotypes in nitrogen allocation to tuber or increased demand for photosynthates due to sink strength and its interaction on late blight incidence. A little change in the rate of leaf photosynthesis per unit area accompanies the substantial genetic increase in yields of wheat, rice, sorghum, soybean, sugarcane, cotton, brassica, and sunflower. However, the higher yields have been associated with a decline in the rate of photosynthesis per unit leaf area relative to that of their progenitors. At early growth stage, a high SLA resulted with a higher NAR on a per unit leaf weight basis as against the later growth stages at which the SLA declined, thereby providing an important means for increased photosynthesis per unit leaf area canopy closure [38].

6. Genetic approach for exploitation of mega environments

6.1 Conventional breeding approach

In traditional breeding, exchange of genes between two plants to produce offspring that have desired traits is done, which also takes a long time to achieve desired results and frequently, traits of interest do not exist in any related species. The development of new cultivars is acyclical process, whereby each cycle consists of three major phases [39–41] such as (i) generating genetic variability through making crosses, inducing mutation, introducing exotic germplasm, and using genetic engineering techniques; (ii) selection and testing of identified superior recombinants; and (iii) release, distribution, and adoption of new cultivars: the yield testing in multi-environment trials (METs). However, the efficiency of a traditional breeding program is less commonly measured in terms of selection gain (or response to selection) obtained in a particular cycle or as the average of a number of cycles, and as benefit/cost ratio, which has been used mostly by economists in impact studies.
6.2 Physiological breeding approach

Although, mega environment concept identifies the homogeneous environments, the yield realization depends on the traits of cultivars, which would enable full utilization of the environment. Donald [42] stated that too little attention had been paid to the basic process governing dry matter production and its transformation into economic yield. Therefore, Donald [43] developed a breeding approach for small grain cereals based on the design of model plants (or) ideotype rather than by the traditional breeding. This approach gained momentum with the finding of a linear relationship between accumulated biomass and intercepted radiation as proposed by Monteith [28, 29]. He introduced the concept of radiation use efficiency (RUE), which represents the efficiency of conversion of radiation energy into biomass. Based on this principle, yield is determined as the product of intercepted radiation, radiation use efficiency, and partitioning of total assimilates. In addition to identifying a genotype, the methodology of physiological breeding aims to identify critical traits of the genotype associated with three drivers of yield and breeding to introgress them into genotypes (Ideotype approach). Fischer [44] has proposed a black box approach, which begins with evaluating a set of genotypes in the presence of a known constraint of interest (e.g., moisture stress/heat stress) and concurrently measuring putatively useful traits in the same genotypes so that the critical traits that have a high genetic correlation with economic performance are identified. This approach has been adopted for identifying genetic variability in water use efficiency [45] and its role in adaptation to drought. Contrarily, the ideotype approach aimed at the physiological understanding to predict what features of an ideal genotype for the target environments might be. This approach is extended by use of crop growth models to simulate the expected consequences of traits in target environments [46, 47]. Rasmusson [48] developed an ideotype for barley consisting of 14 traits, in which two were phenological, and the remaining were morphological. The physiological breeding approach is being adopted in many crops [49] including potato. In potato, Haverkort and Kooman [50] developed a method to define an ideotype of potato for a given situation, which involved accounting for yield defining, limiting, and reducing factors on crop growth parameters and their influence on the length of the growth cycle. In the Indian context, the effect of growing season temperature is expected to reduce the length of the crop cycle from 90 days (Jalandhar) in the North-West Indo-Gangetic Plains to 73 days (Bhubaneswar) in the Eastern Plains with corresponding yield reduction from 5.07 t/ha (Jalandhar) to 3.7 t/ha (Bhubaneswar) on dry weight basis due to higher mean seasonal temperatures prevailed in the Eastern plains. Hence, to develop well-adapted varieties, the variability in drivers of yield in different genotypes has to be studied in the light of the protocol developed by Haverkort and Kooman [50] to develop adapted varieties to the widely different environments prevailing in India. Hence, the physiological understanding for assisting plant breeding has to be prioritized [51].

A critical issue in establishing and conducting a breeding program is determined by resources and choice of breeding strategies to breed and select varieties to meet stakeholder needs. The core breeding as mentioned in the diagram indicated that the generalized sequence of activities, which involves recurrent process of selection and crossing, which aimed to achieve an improvement in overall breeding value of the breeding population with time by increasing the frequency of favorable alleles. The criteria for selection of genotypes vary with the phase of genetic improvement in the breeding program (Figure 5).
The most common, crossing and selection are done to directly develop varieties for commercial release by selecting both parents and their progeny based on either direct estimates of overall economic worth in targeted environments (e.g., based on measurements of economic value per hectare in multi-environment trials) or on measurements of characters correlated with this economic worthiness (selection program @ box 3).

However, in a more strategic phase of genetic improvement (conduct introgression program @ box 5), is to select genotype for use as parents on the basis of a specific character (e.g., resistance to a disease, tolerance to a stress), which is to be introgressed into locally adapted breeding stocks. The donor genotype(s) of the character being introduced may be inferior from an overall agronomic point of view; however, several generations of crossing and selection are required to combine adequate expression of the introduced trait(s) with a satisfactory agronomic background. Hence, the products of an introgression program found to be desirable to enter the “core” program where selection is based on estimates of total economic performance.

**Correlated response to selection for yield gain:** Usually a particular environment is chosen for various reasons (e.g., an experiment station) because of its convenience or representing particular feature of the general region being targeted and also often selected for particular characters (e.g., disease resistance). Gain in the character of economic interest (e.g., mean yield across the targeted environments) from selection for any other character (e.g., yield measured in particular environment, disease resistance rating, a physiological trait) may be considered using the following formula for indirect selection [53]:

\[
CR = ih_i r'_{xy} \sigma_{y}.
\]

where CR is the correlated response of character \(y\), the character of economic interest, from selection for the character \(x\), the character on which selection is based; \(i\) is the standardized selection differential (as \(hx\) is the square root of the heritability for character \(x\), \(r\) ~ is the genetic correlation between character \(y\) and character \(x\), and \(\sigma_{y}\) is the genetic standard deviation for character \(y\).
In all physiological research aimed at an outcome involving genetic improvement, some knowledge of the environmental factors and/or associated physiological processes limiting performance of relevant genotypes in targeted environments (resolution of factor limiting better performance in the target environment @ box 6) such as moisture stress at different phenological periods, low soil fertility, partitioning of assimilate to economically important organs, and radiation interception during reproductive growth (Figure 4). The use of crop growth models to quantitatively assess constraints has been advocated [47], which may have value where highly variable seasonal conditions exist.

**Determining genetic variation for major limiting factors:** There are two factors involved in determining genetic variation. The factor having large effect on the economic performance of significant proportion of genetic population under evaluation at single or multi-environments. There is significant genetic variation in response to the limiting factor for genetic populations being used within or available to the breeding program.

Common procedure to demonstrate genetic variation for a particular constraint is to compare performance of relevant genotypes in one or more environments where performance is markedly affected by that factor, with performance in other “control” environments where the constraint is removed [54]. An alternate approach to identify similarities (or dissimilarities) among trial environments for environmental factors that may cause variation in response among genotypes (e.g., moisture stress at particular phenological stages, soil characteristics, presence of diseases). These similarities are related to relationships among environments for trends in genotype responses. Pattern analysis methodology (e.g., principal component analysis, cluster analysis) may be a useful tool. Identification of environmental factors that vary among selection environments in a similar way as patterns of genotypic response will lead to testable hypotheses about the role of those environmental factors in causing GE interactions.

A selection program in core breeding, GxE interaction is significant, as it typically is, gain from selection will be affected by the choice of environments for selection trials [55]. Ideally, the ranking of genotypes based on results from selection trials should have a high correlation with what would theoretically be obtained if the genotypes were evaluated across all the targeted environments [56]. Therefore, identification of key constraints for which genetic variation in response exists can provide guidance for choosing types of environments for selection trials (identification of target environments for selection trials @box 8). Where GE interaction is insignificant, any small random sample of environments for selection trials may be near optimal, and gains through more deliberate choice may be difficult to obtain. However, where the GE interaction is large, identification of casual factors is expected and one or a couple of factors account for much variation. In a small number of selection trials, which are carefully sited or managed to ensure appropriate levels of the relevant factors, may lead to, on average, significantly greater gains than if a similar number of random environments were used.

Identification of major physiological or environmental factors limiting performance of existing cultivars, coupled with background physiological understanding of plant response to those limiting factors, has led to many suggestions of physiological characters that may be selected by breeders [24, 43, 48]. It has been proposed that first is to use physiological traits as indirect selection criteria in core breeding programs (determine candidate traits for indirect selection @ boxes 7 @ boxes 7 and Assess worth of trait for selection @ boxes 9). The second is to provide objectives of
focused introgression programs (determine candidate traits for indirect selection @ boxes 7 and conduct introgression program @ box 5). Both approaches rely firstly on identifying a trait that affects performance for the character of direct interest (e.g., yield) in targeted environments using black box and ideotype approach [44]. The ideotype model was first advocated by Donald [43], which aimed at the physiological understanding to predict the features of an ideal genotype in the target environments. This approach is extended by use of crop growth models to simulate the expected consequences of traits in target environments [46, 47].

Both the ideotype and black box approaches have some advantages and disadvantages. The ideotype approach (including the use of crop growth models) suffers a major limitation in that it does not, by itself, consider the key genetic parameters such as the traits identified in an ideotype may have little genetic variation or have adverse genetic correlations with other useful traits. The ideotype approach therefore may not identify those traits that could be changed for which gains via breeding may be easiest. Whereas the black box approach partly addresses such issues and it suffers in that the results are relevant only to the genetic population represented by those genotypes being examined. In most physiological studies, the genotypic range is very limited and not representative of breeding populations of relevance to breeding programs. However, the ideotype approach may identify traits of value from outside the germplasm pool being used by breeder [48].

To assess the value of a trait for indirect selection in core breeding programs, the parameters of heritability and genetic correlation with economic characters need to be estimated. These parameters together determine the gain from indirect selection and allow comparison with other selection method. Where GE interaction for the character of economic interest is large, care needs to be taken in determining genetic correlations with putative traits. As per example, osmotic adjustment and early flowering have both been shown to improve yield performance in dry environments [57]. For such traits, it is appropriated to determine the genetic correlation between these characters and economic performance in the full range of target environments. A negative correlation with performance in some environments (e.g., in high rainfall or irrigated environments) may impact on how the traits should be used in selection. In some situations, a negative correlation with yield in some environments and a positive correlation with yield in other environments may justify breeding for specific adaptation if the different types of environments are repeatable and if the effect of the character on economic performance is large.

Physiological breeding approach has been showing increasing impact in countries such as Australia [58] as well as in CYMMYT’s maize and wheat breeding programs. Selection for reduced anthesis-silking interval in tropical maize has significantly boosted yields under drought conditions. In wheat, a new generation of drought adapted lines developed by combining stress adaptive traits (reduce radiation load-wax, pigment composition, leaf angle, and rolling) have been released as part of CIMMYT’s 27th Semi-Arid Wheat Screening Nursery in 2010. The efficient screening has allowed elite genetic resources to be identified in large collections of landraces and using them in strategic crossing [59]. Fine-tuning of phenotyping approaches has also facilitated gene discovery through developing experimental populations in which phenology is controlled, as well as through implementation of rapid screening (e.g., measuring canopy temperature) that permit precision phenotyping of large numbers of genotypes within a time frame that does not confound measurement with environmental fluxes [60].
7. Identification of mega environments for sustainable productivity

The genotype productivity is significantly reduced when the genotype is unable to use the full capacity of favorable environmental conditions. All the varieties are selected for specific agro-ecological conditions and only in such conditions they utilize their maximum genetic potential (with the use of optimal agrotechnology). Jovovic et al. [61] reported the results of 3-year study of productivity for the five leading potato varieties in Montenegro: Riviera and Tresor (early), Kennebec (medium-early), Aladin, and Agria (medium-late). The highest yield of all investigated varieties and localities was measured at variety Agria (30.0 t ha\(^{-1}\)), while the lowest at Riviera (24.6 t ha\(^{-1}\)). In this investigation, Agria variety was favorable for yield of potato tuber. Similarly, the productivity variation in each state belonging to different ecological zone showed significant variation, which indicates that there is scope to increase productivity in the poor yielding zone by introducing high-yielding varieties (AICRIP, 2008), the average productivity differential of the country is wider (18.33 t/ha as against the lowest yield 4.21 t/ha).

Hence, to maximize yield throughout crops in heterogeneous growing regions, despite differences in cultivar rankings from place to place due to GEI, frequently it is necessary to subdivide a growing region into several relatively homogeneous mega environments and to breed and target adapted genotypes for each mega environment. However, the identifying mega environments should fulfill four criteria such as flexibility in handling yield trials with various designs, focus on that fraction of the total variation that is relevant for identifying mega environments, duality in giving integrated information on both genotypes and environments, and relevance for the primary objective of showing which genotypes win where. The AMMI model meets these criteria effectively when the usual biplots are supplemented with several new types of graphs designed to address questions about mega environments. The preliminary results indicated that a small and workable number of mega environments often suffice to exploit interactions and increase yields. Accordingly, the identification of mega environments for the following factors would enhance productivity in any crop, in particular the case study crop potato demands the following criteria to enhance productivity in low land tropics.

7.1 Mega environments for high yield

The spatial and temporal changes in potato cultivation in India have extended its cultivation to stressed conditions or situations, which are not fully conducive for high production efficiency. Hence, there is need to address the sustainability of potato production systems under climate change scenario in view of the expected changes in CO\(_2\) and temperature levels. The increased productivity has to be brought by deployment of varieties matching to its most suitable environment using the concept of mega environments. For which, identification of mega environment for high yield ware, seed, and processing potatoes is essential. Because, the major production constraint is seed material production. Presently, Himachal seed potatoes harvested during October–November cannot be used as seed for plains in the same year, and it can be used only in the next year as the freshly harvested tuber needs at least 60 days to break its dormancy by the time the planting season in plains is over (November). Hence, the mega environment for supplying potato seed tubers during August–September needs to be identified so as to plant them in November in plains. Further, using larger seed tuber for planting consumes lot more investment for seed cost to the farmers, due to which the seed tubers are cut.
into pieces for planting, which causes disease incidence to growing tuber resulting with higher mortality. Hence, the mega environments in which smaller tubers are produced at higher number and can be used for seed tubers so as to avoid cutting of tubers.

7.2 Screening of germplasm for pest and diseases

Being a tropical country, there has been wider variation on climate; yield level, pest and disease prevalence (11–61%) [62]. Improving yield potential combined with biotic and abiotic tolerance is necessitated. In the last five decades, the collection of genetic resources has not acclimatized to varied ecological zone through recurrent mass selection. Study showed that aphid prevalence in the plains is found severe during December–March, during the peak period of potato cultivation at plains in India. This causes severe virus transmission and poor yield in potato. Hence, the seed production program is restricted only at higher hills (>2000 m) where the potato infestation by aphid is very low due to low temperature, but demands long maturity genotypes. For plains, early maturing genotypes are required to raise due to short winter period, which needs to identify an aphid-free mega environment in plains for rising short duration seed potato and supply to plains and vice versa.

7.3 Developing homomorphic floral genotype for high TPS production

The genetic base of *Tuberosum* has also been widened through creation of broad based populations of long day adapted *S.tuberosum* subsp. *andeigena*, and long day adapted *S.phureja/S.stenotomum* [63]. The cultivated potato (tetraploid) is self-incompatible, has very narrow genetic base causing crop susceptible to several diseases. Multiplication through seed is carrier of virus as it happens through tuber multiplication. Hence, identification of mega environment for self-compatible lines selection where homomorphic flower with having early bulking ensures self seeds under natural condition. Although, true potato seed has added advantage of non-transfer of virus to the next generation, low mass, and easy transport and saving of 30–35% input cost in using tubers as planting material. Developing short-duration TPS families, early foliage maturity, and early tuber bulking would be ideal for TPS production. According to Gopal [64], out of 133 accessions tested for possibility of producing hybrid seed and open pollinated seeds, only five accessions, namely CP1330, Hibinskyrany, I-1039, yy6, and yy12, were promising for production of open pollinated seeds as these genotypes produced more than five berries/plants with more than 200 seeds/berries. The accessions showed profuse flowering genotypes (female) used in hybrid seed production found and were late foliage maturing and presumed to be unsuitable for plains for TPS production. In India, *S.tuberosum* sub sp. *andigena* was mainly used as parent to generate genetic variation for short day condition. However, it also tends to impart late maturity in the progeny due to which 11 out of 21 cultivars released for subtropical condition are medium to late maturing type. Though the ssp. *andigena* has been used to some extent in the Indian potato breeding, all the improved varieties produced true potato seeds in only hills and majority of them do not set flowers at plains under natural condition.

7.4 Heat and drought-tolerant genotypes

All over the world, using wild species in potato crop improvement is relatively slow and conservative [65] might be due to differences in ploidy, sterility barriers, etc. Sterility and tetraploidy in conjunction with a high level of heterozygosity greatly
reduce the ability to use traditional methods of breeding, specifically hybridization and selection, for potato improvement. Joseph et al. [66] screened the same set of potato genotypes at three locations varying in altitudes (Kufri, Modipuram, and Jalandar), temperate and subtropical plains of India. The magnitude of genetic parameters was found similar at Modipuram and Jalandar and higher than the location Kufri, which indicates either one location can be used for screening of germplasm or separate screening is needed for higher altitude location. Further, the tuber yield did not have significant correlation with plant height or number of leaves per plant in subtropical plains (Modipuram and Jaladhar) as against the location Kufri, where the higher number of shoots had positive correlation with tuber yield \( r = 0.55 \) at hill conditions [66]. Raj et al. [67] evaluated heat-tolerant genotypes and varieties of potato against leaf hopper and mite at one location Modhipuram and found that genotype HT/92–621, the most efficient against hopper burn. Patel et al. [68] evaluated eight potato varieties assessing their suitability for very early and late harvest for premium market price in Gujarat condition, the results revealed that there was significant effect for genotype and environment interaction for both harvest. K. Phukraj had wide adaptability, as against K. Badsha, which was ideal stable genotype for late harvest, and K. Badsha and K. Jawahar were adapted to favorable environments only. For long time, there was few photo-insensitive genotypes of potato recommended for commercial cultivation, large part of peninsular region of India unfit for potato cultivation. Minhas et al. [69] recommended K. Surya for early maturing, heat-tolerant potato for North Western plains and Peninsular India. The tuberization ability of K. Surya was found higher at 24°C over 27°C [69] due to high rate of photosynthesis [70] under multi-location trials.

7.5 Processing genotypes

Considering processing genotypes, the relationship between specific gravity and dry matter content of potato is vital traits, and the relationship has been found to vary with the variety, location, season, and the year of cultivation [71]. Kumar et al. [70] reported that under water weight basis for conversion of specific gravity, dry matter content, and starch content in potato grown in North Indian plains. The dry matter content and the amount and kind of sugar in particular cultivars are inherited characteristic and influenced by cultural or environments [72]. The influence of short day condition on dry matter distribution of tuber at Modhipuram was found the highest distribution at stem end as compared with pith region in K. Chipsona and Atlantic with the highest dry matter content (17%). Patel et al. [73] reported varietal variation for yield, French fry grade tuber at three locations in Gujarat, and it was due to genotype and environment interaction and none of the genotypes performed better at three locations. Pandey et al. [74] screened processing quality potato genotypes under different hilly locations and found that K. Himasona recorded the highest tuber yield and processing grade tubers with field resistance to late blight at all locations in India.

7.6 Nutrient use-efficient genotypes

In potato, the classification of early, mid, and late maturing genotypes characterized to subtropical and temperate climate suited respectively based on the early dry matter accumulation for early harvest of tubers. Singh et al. [75] assessed the performance of early, medium, and late maturing genotypes of potato under subtropical plains, the
results revealed that the dry matter accumulation in early genotype (K.Asoka) was at par with medium (K. Giriraj, K. Sherpa and K. Phukraj) and late maturing genotype (K.Sinduri) at 28 days after planting. At 39 days, the early maturing genotype at par performed with medium (K.Sherpa and K.Phukraj) and late maturing genotype (K.Sindhuri), where K. Giriraj, K. Lauvkar performed below par with early maturing type. Up to 71 days growth, the trend was similar as that of 39 days except that the genotype K. Giriraj pickup its dry matter accumulation and at par with early maturing genotype (K.Ashoka) and the late maturing genotype exhibited exorbitant level of accumulation over early and medium maturity group. From 81 to 91 days growth, the accumulation of dry matter in early maturing genotypes was found lower than medium maturing (except K.Lauvkar) and late maturing genotypes. At 115 days, there was no accumulation of total dry matter in the early and medium maturing genotypes except late maturing in which dry matter accumulation process continued. This indicates that dry matter accumulation is genotype-specific but not in early and medium maturing group. According to environment, few genotypes of medium maturity can also suit for early maturing group, for which mega environment concept facilitates screening of genotypes for different maturity group at different environments. The genotype-specific variation in dry matter accumulation has been reported for rain-fed condition, heat stress area [66], frost stress areas, disease stress, and nutrient use efficiency [76], which vary from location to location of potato growing regions, as the uptake of soil nutrients or water is done by contact between the root cells with soil nutrients. Because the nutrient uptake efficiency of plant increases when the root grows to the area where nutrient or water is available, i.e., root interception. The contact also occurs due to the movement of nutrients from the soil to root surface for which the soil must have more nutrient content. The movement of nutrients from soil to roots occurs in both mass flow and diffusion method [77]. In the former, the nutrients flow from the soil toward the roots in solution form, whereas in the latter, the nutrients flow to the adjacent areas where its concentration is lower. At low as well as optimum soil nutrient levels, the soil diffusion supplies much higher ion quantities from soil to roots than mass flow. Hence, diffusion is therefore fundamental importance for the availability of nutrients of plants growing in soil [78]. Hence, not only soil water and nutrients but also biotic stress and heat-related stress cause changes in plant system and which alter the uptake of nutrients for dry matter accumulation in potato, ultimately deciding the yield potential. Hence, mega environment for crossover interaction with different maturity of potato is to be identified.

8. Strategy for exploitation of physiological breeding in Indian potato

In addition to identification of mega environments, development of improved varieties with high yield potential is determined by the canopy cover, radiations use efficiency, and partitioning ratio of genotypes [5]. Under unstressed condition, the radiation use efficiency remains constant in time both for total [5] and tuber dry matter production in potato. Even the two high-yielding genotypes follow different strategy among them to result into high tuber yield [31], as the potato cultivar “Moemoe” had better yield primarily through an increase in tuber numbers as against “Moonlight,” which had produced more tubers and increased tuber weight in response to irrigation. The estimated mean water use efficiency (WUE) ranged from 13.1 g/lit (Agria) to 6.4 g/lit (Tutaekuri), which equates to 7.6 and 15.6 lit, respectively, to produce a 100 g tuber. This value is much lower than an estimate of the mean global
virtual water content of 25lit for a 100 g potato tuber [79]. Hence, the physiological traits of the cultivar Agria would be an index for screening genotypes for drought environments and for WUE efficiency enhancement in Indian potatoes. Ninety-eight germplasm lines were screened for water use efficiency and transpiration rate and found wider variation water use efficiency in Indian potato [69].

Leaf character: The amount of total radiation intercepted by green active foliage depends on the amount of solar radiation and on the proportion that intercepted (based on leaf area index, leaf angle, and scattering nature of leaf). Hence, the need of selection for several traits into one genotype is must to attain higher yield. Considering critical traits, optimum leaf temperature for photosynthesis in potato has been reported to range between 16°C and 25°C, and the increase in leaf temperature beyond this level drastically reduces the photosynthetic rate [80]. There has been wider variation in leaf number per plant, which ranges from 30.3 (Granola) to 93.3 (Agria) [81], and progeny selection for greater leaf photosynthetic rate and leaf shape [82] indicated that they are heritable in nature. Larger surface area in leaves has been associated with increasing light absorption and shown reduced or almost zero expression of lobes and edges in potato [83]. The presence of complex edges and lobes in larger leaves will enable them to disperse absorbed heat very rapidly, which emphasize that the presence of lobes and edges on margin of leaves of potato would help in heat release mechanism at heat stress area. Similarly, waxy surface is usually observed in younger leaves functioning to prevent (or) minimize the transpiration rate of the plant. On the contrary, the smaller leaf area under stress in a range of species is reported to be associated with greater vein density that may contribute to increased abiotic stress tolerance [84]. In several species, the vein density is correlated with hydraulic conductivity of water and maximum photosynthetic rate in leaves [85]. Broader leaves are stabilized by a set of major parallel veins, narrow and mid-sized leaves are stabilized by a central midrib with rectangular branching laterals [86]. The venation systems of leaves are independent of size and which also reveal the water transport system in the plant.

Leaf area index: A high value of LAI has been suggested to indicate a denser or healthier crop canopy; while a low value represents sparse or or drier canopy. The LAI ranged from 1.40 (Dakchip) to 6.60 (Pungo) and have been observed among the potato genotypes. Atlantic, Chipbelle, and DTO-33 showed no decline in their LAI up to 73 days after planting under abiotic stress environment, indicating its tolerance ability [87, 88]. Crop growth rate increases with leaf area index, particularly at early growth stages. Because the relative increases in the interception of photosynthetically active radiation (IPAR) are largest when leaf is small [89]. The relative rate of leaf area expansion of potato decreased with thermal time, but the reduction was nearly linear up to a leaf area index (L) of 1.0; however, single leaf area of potato increased nearly linearly with thermal time from 5 to 15 m²kg⁻¹ at 50% emergence, from 20 to 25 m²kg⁻¹ at 155°Cd, and then decreased slightly [90]. Potato genotypes with warmer canopies under irrigated conditions are predicted to be less susceptible to drought than genotypes with cooler canopies indicating the rate of transpiration-driven cooling of the leaves.

Canopy photosynthesis (CA): CA on ground cover basis differed significantly among the genotypes, and Pungo had higher values than other genotypes, which ranged between 1.72 and 4.34 g CO₂ m⁻² hr⁻¹ during 1984 and 1985, respectively [87]. Mean adaxial and abaxial stomatal conductance was 0.86 and 1.46 cm sec⁻¹. Stomatal conductance did not appear to limit gas exchange in potato leaves. Dry matter partitioning to tubers ranged from 8.9% (Pungo) to 55.5% (Atlantic) 67 DAPS and
the tuber yield ranged from 9.6 to 27.8 MT/ha, indicating the suitability of cultivar Atlantic for growing in a warm climate. Under stress environment, the leaf area index (LAI) of early cultivars had increased from a value of 3.9 to 5.3 accounting 7% greater cumulative light interception, which consequently enhanced the transpiration rate under moisture stress condition declines light use efficiency and low harvest index in potato. In cv. Dasiree, the dry matter partitioning pattern exhibited earlier and faster tuber filling than the cultivars of same maturity group, where a greater proportion of assimilates diverted toward leaf growth [91].

Root traits: Wishart et al. [92] observed wider variation in root traits of a range of potato genotypes including the European tetraploid potato, diploid, and Neotuberous lines The total root length per plant varied from 38 m (Tuberosum variety Pentland Dell) to >100 m (Phureja variety Mayan Twilight). Root thickness and distribution also varied significantly among cultivars with the Phureja line (Mayan Gold) having the longest and thinnest roots (based on ratio of stolon root number with stolon root weight). Number of stolon roots and basal roots among the cultivars (Phureja lines, Mayan Gold) indicated them having significantly more of both these root groups. Further, a significant difference in the relative proportions of basal to stolon root was apparent with Phureja line and Mayan Gold. The largest proportion of basal roots of these genotypes as compared with the other cultivars tested suggested the existence of potential genetic difference in resources partitioning. Hence, improvement in root traits such as root depth and root length density [93] is important for developing cultivars for rain-fed condition. Studying root system in potato is complicated, root-pulling resistance has been proposed as a practical measure to quantify root development. A positive correlation was found between root pulling resistance and tuber yield was noted [94]. Root mass correlates well with leaf mass and tuber yield [95] and justifies that the erectophile, smaller but greater in number of leaves per plant, suits good for rain-fed crop.

Photosynthesis factors: Bhagsari [87] compared the single leaf net photosynthesis determined at 30 ± 2°C by enclosing attached fully mature leaves of sweet potato, cassava, and yam and found the 1.10, 0.70, and 0, 30 mg CO$_2$ m$^{-2}$ s$^{-1}$, respectively. The mean canopy photosynthesis rates, expressed on leaf area basis, for sweet potato, cassava, and yam, were 0.18, 0.38, and 0.17 mg CO2 m$^{-2}$ s$^{-2}$, respectively. With increase in leaf age from 20 to 60 days, the single leaf photosynthetic rate increased in all these crops; however, partitioning of assimilates to root was found higher in cassava. The photosynthetic rate can be improved through breeding [96], and progress could be achieved for high photosynthetic CO$_2$ exchange rate [97]. Cieply [98] concluded that assimilation rates can be used as a physiological criterion for rapid selection in potato breeding. Mol and Henniger [99] measured rates of $^{14}$CO$_2$ uptake by 18 clones of potato under standard conditions. The stomatal number per leaf at upper surface was found to range from 4 (A6948) to 50 (A66107–51) among the four genotypes evaluated and 130 and 204 at lower surface of the respective genotypes. Similarly, the stomatal apparatus area also showed variation ranging from 0.1 to 2.2 at upper surface and 6.8 and 9.6 at lower surface of respective potato clones. However, the CO$_2$ uptake was found higher in clone A-6948 (9.2) as compared with A-66107-51 (7.6 mg CO$_2$mg$^{-1}$ chl h$^{-1}$), which gives a surprising contribution to total carbon assimilation that cv. Lemhi had an unusually high rate of CO$_2$ assimilation through the upper leaf surface, and A6948–4 an unusually high rate through the lower leaf surface. Hence, with proper breeding approach, these two traits can be combined for enhancing high carbon assimilation rates of Lemhi’s through upper leaf surface and A6948–4 through lower leaf surface.
9. Conclusion

Every crop encounters several production constraints from seed to harvest, which is tactfully manipulated by researcher by developing genotype and suitable production technology for varied environments, which frequently reflect wider yield variations. Because, the genotype by environment interaction reduces the association between the phenotypic and genotypic values and leads to bias in the estimation of gene effects and combining ability for various characters that are sensitive to environmental fluctuations less reliable for selection. In maize, commercial grain yields have improved nearly sixfold and the genetic component of the improvement has been estimated as approximately 60%. The changes in leaf canopy size and architecture account for only a minor portion of the improvement. The majority of the improvement in source capacity is due to visual and functional stay-green. Functional stay-green and the sink establishment dynamics still represent opportunities for yield improvements [100]. The 2.13-fold increase in ERA hybrid grain yield represents a 113% improvement in dry matter accumulation (DMA). The increase in DMA (i.e., the “source”) can be attributed, in part, to quantifiable changes in light interception due to increased leaf area index (LAI) and changes in light utilization due to more erect upper leaves. These improvements on the source side were accompanied by improvements in sink establishment dynamics permitted plants to maintain harvest index (HI) of ~50% even when grown under stress conditions.

In potato, a hypothetical attainable yield estimated for different kharif growing region of India with existing growing period by changing canopy cover (100%) duration extended for 10–40 days, the GDD accumulation during the growing season could be enhanced up to 800 (Dharwad), 585 (Hassan), 406 (Ooty), 602 (Shimla), and 886 (Srinagar) additionally. Under the condition of harvesting of the additional heat units and converted in terms of dry matter, the attainable yield (25.4, 28.7, 31.7 and 34.7 t/ha, respectively) at Dharwad, Shimla (31.9, 34.9, 38.3. and 42.0 t ha$^{-1}$) could be obtained. Hence, identification mega environments facilitates the genotypic effect stable and environment effect zero for different production aspects. As physiological breeding coupled with mega environments identification would result in both genotypic and phenotypic effect stable, it can be considered as a sustainable smart farming.

10. Future prospective

In order to exploit yield determinants, the future perspective is to identify mega environments for trait of interest, breed varieties with identified traits, testing of developed varieties specifically for single, multiple, and mega environments based on the traits segregation pattern rather than testing them across environments without targeting the traits of interest in the beginning of breeding program.
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