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# Association and Path Analysis among Sugar Yield and Components under Two Water Regimes in Sugarcane (*Saccharum* spp. Complex)

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***Authors' contributions***

*This work was carried out in collaboration between all authors. Author GSS conceptualized, designed and managed the analyses of study, authors VT and RPS performed the statistical analysis, wrote the first draft of the manuscript. Authors HS and LK managed the literature searches. All authors read and approved the final manuscript.*

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## ABSTRACT

Thirty sugarcane (*Saccharum* spp. hybrid complex) elite clones/varieties were evaluated for different sugar yield and other quality traits under two water regimes. Analysis of variance revealed significant differences among clones tested for different characters in both normal ($E_1$) and water stress ($E_2$) environments. Association studies showed that pol (%) in juice at 12 months had maximum direct effect on commercial cane sugar (CCS) (t/ha) followed by brix (%) at 10 months, purity (%) at 10 months, pol (%) in juice at 10 months, fibre (%) at harvest, pol (%) cane percentage and juice extraction (%) at 10 months under water stress ($E_2$) environment. CCS (%) at 12 months had maximum positive direct effect on CCS (t/ha) under normal ($E_1$) conditions followed by pol (%) cane at harvest, pol (%) in juice at 12 months, juice extraction (%) at 10 months and 12 months and

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fibre (%) at harvest had negative direct effect. Under water stress ($E_2$) conditions, pol (%) in juice at 12 months had maximum direct effect on CCS (t/ha) followed by brix (%) at 10 months, purity (%) at 10 months, pol (%) in juice at 10 months, fibre (%) at harvest, pol (%) cane percentage at harvest and juice extraction (%) at 10 months. In present study revealed that traits like brix (%) 10 months, pol (%) in juice, pol (%) cane and juice extraction (%) be emphasized for sugar yield (t/ha) improvement under water stress ($E_2$) conditions.

*Keywords: Sugarcane; juice quality; correlation and water stress.*

## 1. INTRODUCTION

Sugarcane (*Saccharum* spp. complex) is a widely grown crop in both tropics and sub tropics as a source of energy providing food and fuel. In India, it is an important cash crop which plays a pivotal role in Indian agriculture and industrial economy. Sugarcane is used for seed, green fodder, chewing, production of sugar and alternative sweetner (Jaggary etc.) and juice etc. Sugar industry is the second largest agro based industry after textile and contributes significantly to the value of total agricultural output of country [1]. Quality of sugar cane means the sucrose content in cane which is an important factor in sugar production. Factors that affect cane quality are seed material used, age of crop, fertilizers and water management, control of insect pests and diseases and maturity of cane [2]. In addition to the above factors weather conditions prevailing during cane crop season have significant impact on its productivity both in terms of cane yield, quality and sugar yield. Cane quality in terms of sucrose content is also affected by climatic factors like rainfall, maximum and minimum temperature, relative humidity and sunshine [1]. A dry and cool climate is required from September to December for optimum maturity of sugarcane. The temperature between 15 to 25°C helps in synthesis of sucrose in cane. Another factor affecting maturity of sugarcane crop is soil moisture. The gradual withdrawal of irrigation during ripening phase is known to help in accumulation of more sugar and heavy rainfall or excess irrigation in the month of September and October adversely affects the quality of cane [1,3].

With the increases in climate change, soil water deficit is one of the biggest challenges for crop productivity. Abiotic stresses are the main causes of major crops productivity losses that cause negative impacts on crop adaptation and productivity [4]. Due to glycophytic nature of sugarcane, drought conditions interfere with sugar production by affecting growth rate, yield of the cane, juices of lower sucrose contents, purity, higher acidity and the sucrose content of the stalk [5-6]. Thus drought may reduce sugarcane yield up to 50% or even more. Sugarcane drought tolerant varieties have the ability to reduce transpiration losses and these varieties maintain a fairly adequate absorption of water from the soil. So, there is an urgent need to identify sugarcane varieties adapted to moisture stress in order to sustain sugarcane production and sugar recovery in the country. Genetic improvement in cane and sugar yield may be achieved by targeting traits closely associated with sugar yield CCS (t/ha). Knowledge of interrelationship among the various characters and their direct and indirect effects is considered to be important in devising proper selection strategies in sugarcane breeding for sugar yield improvement under water stress conditions. So, to identify the different crop quality parameters responsible for the higher sugar productivity and growth under water stress conditions, the present study was conducted to assess interrelation patterns of different quality parameters with sugar yield (t/ha) under normal irrigated ($E_1$) and water stressed ($E_2$) conditions.

## 2. MATERIALS AND METHODS

The experimental plant material consisted of 30 sugarcane genotypes comprising nine commercial varieties ( Co238, CoJ88, CoS8436, CoPb91, CoPb92, CoPb93, Co118, CoJ85 and CoJ64), twelve local elite Clones (CoPb13181, CoPb10181, CoPb13182, CoPb11214, CoPb11211, CoPb12181, CoPb12182, CoPb14212, CoPb14211, CoPb12212 and L818/07), five new introductions (KV2012-1, KV2012-2, KV2012-3, KV2012-4 and KV2012-5) and four ISH clones viz. ISH148, ISH159, ISH135 and ISH07. All the experimental material was planted in randomized block design having a plot size of 21.6 $m^2$ with two replications under normal ($E_1$) and water stress ($E_2$) environments. Three budded setts of each genotype at the rate of 12 buds per running meter were planted. The data from different clones were recorded for quality parameters viz. brix at 10 and 12 months (%), pol at 10 and 12 months (%), juice extraction at 10 and 12 months (%), purity at 10 and 12 months, commercial cane sugar (t/ha) at 10 and 12 months (%), fibre content (%) at harvest, pol (%) cane at harvest and CCS (t/ha) was calculated from CCS (%) and cane yield (t/ha) at harvest from both the normal ($E_1$) and water stress ($E_2$) environments. All the quality parameters were recorded following standard procedures viz. Brix, pol and purity percent [7], fibre content [8], however, CCS (%), pol (%) cane and sugar yield (t/ha) were worked out as per [9] given below:

### 2.1 Commercial Cane Sugar (CCS) (%)

Commercial cane sugar (%) was calculated from the pol (%) and purity (%) at 10 and 12 months in juice using following formula:

$$\text{CCS (\%)} = \frac{0.292*\text{Pol \%} - ((0.035*\text{Purity \%}) - 1))}{\text{Purity \%}} \times 100$$

### 2.2 Pol (%) Cane

Pol in cane (%) at harvest represents the total pol present in the cane. It is calculated by adding the pol percent in juice and pol percent in bagasse. For pol percent in bagasse 250 g bagasse dipped in 2 litres distilled water was processed in Rapipol extractor for 15 minutes. The water containing bagasse juice was cleared with basic lead acetate and was thoroughly mixed by manual shaking. After having the precipitation, the juice was filtered to collect purified juice. The filtrate was collected, and its polarization was recorded digital automatic polarimeter which gives the value of pol percent in bagasse. Pol in cane at harvest (%) was calculated by following formula:

Pol (%) in cane = Pol in juice (%) + Pol in bagasse (%)

### 2.3 Commercial Cane Sugar CCS (t/ha)

Commercial cane sugar (CCS) at harvest was calculated using cane yield (t/ha) and commercial cane sugar percent (CCS%) as recorded earlier by using following formula:

CCS (t/ha) = [Cane yield (t/ha) × CCS (%)]

### 2.4 Statistical Analysis

The mean values of all the traits from each genotype in each replication were used for analysis of variance as per Fisher [10] carried out with CPCS1 software [11]. However, phenotypic and genotypic correlation coefficients of different traits with cane yield were worked out by the formulae suggested by Al-Jibouri [12] and path coefficient analysis was done following Dewey and Lu [13] under normal ($E_1$) and water stress ($E_2$) environments using MVM software [14] and interpretations were made accordingly.

## 3. RESULTS AND DISCUSSION

The analysis of variance revealed significant differences among the clones for sugar yield (t/ha) and other quality traits studied under both normal ($E_1$) and water stress ($E_2$) environments. Thus, the clones were genetically divergent. The significant genotypic effects indicated genetic variability among the genotypes and the possibility of genetic improvement in most of the traits studied through selection [15-16]. The relatively large genotypic mean squares indicated that clones differed in their potential for the traits. Genetic variance is important as it describes the amount of genetic variation present for the trait. High genetic variance relative to environmental variance for number of millable cane and stalk weight in the plant cane and for stalk diameter and stalk weight indicates that these traits were affected less by environmental effects [17]. Association studies among quality traits, at genotypic level revealed that CCS (t/ha) which is a function of cane yield and CCS (%) exhibited significant positive association with other quality traits like pol per cent in juice at 10 months (0.385 and 0.532), purity percent at 10 months (0.875 and 0.712), CCS percent at 10 months (0.465 and 0.608), brix percent at 12 months (0.390 and 0.611), pol (%) at 12 months (0.559 and 0.776), purity (%) at 12 months (0.490 and 0.752), CCS percent at 12 months (0.586 ad 0.803) and pol (%) in cane (0.586 and 0.817) under both $E_1$ and $E_2$ environments, respectively and with brix percent at 10 months (0.335) and fibre percent at harvest (0.414) under water stress ($E_2$) conditions. Sreekumar [18] and Thippeswamy [19] reported that sugar quality parameters show highly significant positive genetic correlations with each other and with sugar yield revealing that any of these juice quality traits could be considered for selection

**Table 1. Genotypic and phenotypic correlation coefficients among different quality traits of sugarcane under normal ($E_1$) and water stress ($E_2$) environments**

| Traits | Env. | Brix at 10 months (%) | Pol at 10 months (%) | Extraction at 10 months (%) | Purity at 10 months (%) | CCS at 10 months (%) | Brix at 12 months (%) | Pol at 12 months (%) | Extraction at 12 months (%) | Purity at 12 months (%) | CCS at 12 months (%) | Fibre at harvest (%) | Pol cane at harvest (%) | CCS at harvest (t/ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Brix at 10 | **E1** | | 0.9721** | -0.253 | -0.0633 | 0.9419** | 0.3706** | 0.3736** | -0.1539 | 0.1073 | 0.3534** | -0.1336 | 0.3533** | 0.1919 |
| months (%) | **E2** | | 0.9526** | 0.2814* | 0.0718 | 0.8990** | 0.5496** | 0.4273** | -0.2245 | 0.0381 | 0.3755** | 0.4827** | 0.4518** | 0.3354** |
| Pol at 10 | **E1** | 0.9019** | | -0.1806 | 0.1739 | 0.9944** | 0.4892** | 0.5520** | -0.0296 | 0.2754* | 0.5425** | -0.0921 | 0.5424** | 0.3853** |
| months (%) | **E2** | 0.9313** | | 0.3572** | 0.3701** | 0.9897** | 0.6428** | 0.5935** | -0.0792 | 0.2636* | 0.5591** | 0.5172** | 0.6373** | 0.5324** |
| Extraction at | **E1** | -0.2265 | -0.2116 | | 0.2981* | -0.1443 | -0.2284 | -0.3076* | -0.3097* | -0.2429 | -0.3174* | 0.3831** | -0.3174* | 0.2652* |
| 10months (%) | **E2** | 0.1479 | 0.2273 | | 0.3202* | 0.3816** | 0.1367 | 0.1306 | -0.3357** | 0.0564 | 0.125 | 0.3714** | 0.203 | 0.3186* |
| Purity at 10 | **E1** | -0.1896 | 0.2509 | 0.0369 | | 0.2772* | 0.5575** | 0.8017** | 0.4866** | 0.7107** | 0.8415** | 0.1662 | 0.8412** | 0.8757** |
| months (%) | **E2** | 0.0277 | 0.3879** | 0.2458 | | 0.4987** | 0.4448** | 0.6370** | 0.4160** | 0.7130** | 0.6764** | 0.2489 | 0.7148** | 0.7121 ** |
| CCS at 10 | **E1** | 0.8038** | 0.9819** | -0.1921 | 0.4288** | | 0.5334** | 0.6223** | 0.0276 | 0.3460** | 0.6177** | -0.0714 | 0.6177** | 0.4658** |
| months (%) | **E2** | 0.8576** | 0.9860** | 0.2531 | 0.5351** | | 0.6656** | 0.6524** | -0.008 | 0.3615** | 0.6274** | 0.5166** | 0.7040** | 0.6082** |
| Brix at 12 | **E1** | 0.2284 | 0.3448** | -0.1734 | 0.2613* | 0.3747** | | 0.8778** | 0.2092 | 0.0828 | 0.7864** | 0.2336 | 0.7864** | 0.3905** |
| months (%) | **E2** | 0.4527** | 0.5176** | 0.1041 | 0.2896* | 0.5234** | | 0.9215** | 0.1498 | 0.4375** | 0.8679** | 0.4753** | 0.9373** | 0.6117** |
| Pol at 12 | **E1** | 0.2738* | 0.4350** | -0.1419 | 0.3805** | 0.4791** | 0.7911** | | 0.1202 | 0.5498** | 0.9861** | 0.2221 | 0.9861** | 0.5597** |
| months (%) | **E2** | 0.3793** | 0.5089** | 0.1434 | 0.4346** | 0.5450** | 0.8754** | | 0.3682** | 0.7517** | 0.9927** | 0.5294** | 0.9215** | 0.7766** |
| Extraction at | **E1** | -0.0587 | -0.006 | 0.0229 | 0.1002 | 0.0173 | 0.0397 | 0.0288 | | -0.0904 | 0.0809 | 0.2116 | 0.0809 | 0.1984 |
| 12 months (%) | **E2** | -0.235 | -0.1256 | -0.1755 | 0.2482 | -0.0701 | 0.2154 | 0.3228* | | 0.6165** | 0.4242** | 0.1818 | 0.3031* | 0.2447 |
| Purity at 12 | **E1** | 0.1178 | 0.2277 | 0.0094 | 0.2782* | 0.2620* | -0.0829 | 0.5431** | -0.0044 | | 0.6804** | 0.0698 | 0.6800** | 0.4906** |
| months (%) | **E2** | 0.0308 | 0.187 | 0.1207 | 0.4069** | 0.2504 | 0.1856 | 0.6368** | 0.3220* | | 0.8224** | 0.4235** | 0.8105** | 0.7526** |
| CCS at 12 | **E1** | 0.2632* | 0.4246** | -0.1177 | 0.3856** | 0.4695** | 0.6482** | 0.9786** | 0.0219 | 0.7041** | | 0.2064 | 0.9245** | 0.5866** |
| months (%) | **E2** | 0.3342** | 0.4781** | 0.1486 | 0.4586** | 0.5223** | 0.7861** | 0.9869** | 0.3404** | 0.7524** | | 0.5289** | 0.9351** | 0.8034** |
| Fibre at | **E1** | -0.0923 | -0.0605 | 0.2438 | 0.0773 | -0.0425 | 0.0755 | 0.0985 | 0.1537 | 0.0628 | 0.0973 | | 0.2063 | 0.0426 |
| harvest (%) | **E2** | 0.2768* | 0.2722* | 0.3254** | 0.0648 | 0.2584* | 0.2612* | 0.3658** | -0.0021 | 0.3304** | 0.3810** | | 0.5999** | 0.4145** |
| Pol cane at | **E1** | 0.2632* | 0.4246** | -0.1177 | 0.3856** | 0.4695** | 0.6481** | 0.9785** | 0.0219 | 0.7041** | 0.9512** | 0.0972 | | 0.5866** |
| harvest (%) | **E2** | 0.3205* | 0.4333** | 0.1557 | 0.3875** | 0.4651** | 0.6323** | 0.7866** | 0.2284 | 0.5961** | 0.7951** | 0.3101* | | 0.8173** |
| CCS at | **E1** | 0.1183 | 0.3255** | 0.0749 | 0.4831** | 0.3965** | 0.3862** | 0.5488** | 0.0799 | 0.3673** | 0.5528** | 0.0134 | 0.5528** | |
| harvest (t/ha) | **E2** | 0.2939* | 0.4770** | 0.2713* | 0.5592** | 0.5396** | 0.5617** | 0.7578** | 0.1887 | 0.6359** | 0.7817** | 0.3277* | 0.6372** | |

*Critical value of 'r' at 5%=0.2541 and at 1%=0.3301, above diagonal Genotypic correlation coefficients*

**Table 2. Estimates of direct and indirect effects of different quality traits of sugarcane genotypes on commercial cane sugar (CCS) (t/ha) at phenotypic level under normal ($E_1$) and water stress ($E_2$) environments**

| Traits | Env. | Brix at 10 months (%) | Pol in juice at 10 months (%) | Extraction at 10 months (%) | Purity at 10 months (%) | CCS at 10 months (%) | Brix at 12 months (%) | Pol in juice at 12 months (%) | Extraction at 12 months (%) | Purity at 12 months (%) | CCS at 12 months (%) | Fibre content at harvest (%) | Pol in cane at harvest (%) | Correlation with CCS (t/ha |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Brix at 10 months (%) | $E_1$ | **8.735** | -23.010 | -0.036 | -0.129 | 14.423 | -0.798 | 3.143 | -0.003 | -0.058 | -1.229 | 0.009 | -0.092 | 0.1183 |
| | $E_2$ | **-0.783** | 1.2585 | 0.012 | 0.000 | -0.456 | 0.457 | -4.165 | 0.013 | -0.051 | 3.984 | 0.008 | 0.015 | 0.2939 |
| Pol in juice at 10months (%) | $E_1$ | 7.878 | **-25.512** | -0.034 | 0.171 | 17.619 | -1.205 | 4.993 | -0.000 | -0.113 | -1.982 | 0.006 | -1.495 | 0.3255 |
| | $E_2$ | -0.730 | **1.351** | 0.019 | 0.0001 | -0.524 | 0.523 | -5.589 | 0.007 | -0.309 | 5.700 | 0.007 | 0.021 | 0.4770 |
| Extraction at 10 months (%) | $E_1$ | -1.978 | 5.399 | **0.163** | 0.025 | -3.447 | 0.606 | -1.629 | 0.001 | -0.004 | 0.549 | -0.024 | 0.414 | 0.0749 |
| | $E_2$ | -0.116 | 0.307 | **0.084** | 0.0001 | -0.134 | 0.105 | -1.574 | 0.010 | -0.199 | 1.771 | 0.009 | 0.007 | 0.2713 |
| Purity at 10 months (%) | $E_1$ | -1.655 | -6.401 | 0.006 | **0.683** | 7.695 | -0.913 | 4.368 | 0.005 | -0.138 | -1.800 | -0.007 | -1.357 | 0.4831 |
| | $E_2$ | -0.021 | 0.524 | 0.020 | **0.0003** | -0.284 | 0.292 | -4.773 | -0.014 | -0.673 | 5.467 | 0.001 | 0.019 | 0.5592 |
| CCS at 10 months (%) | $E_1$ | 7.021 | -25.050 | -0.031 | 0.293 | **17.944** | -1.310 | 5.500 | 0.001 | -0.130 | -2.192 | 0.004 | -1.653 | 0.3965 |
| | $E_2$ | -0.672 | 1.332 | 0.021 | 0.0002 | **-0.531** | 0.528 | -5.986 | 0.004 | -0.414 | 6.226 | 0.007 | 0.023 | 0.5396 |
| Brix at 12 months (%) | $E_1$ | 1.994 | -8.796 | -0.028 | 0.178 | 6.724 | **-3.496** | 9.081 | 0.002 | 0.041 | -3.026 | -0.007 | -2.282 | 0.3862 |
| | $E_2$ | -0.354 | 0.699 | 0.008 | 0.0001 | -0.278 | **1.010** | -9.614 | -0.012 | -0.307 | 9.371 | 0.007 | 0.031 | 0.5617 |
| Pol in juice at 12months (%) | $E_1$ | 2.391 | -11.097 | -0.023 | 0.260 | 8.597 | -2.765 | **11.480** | 0.001 | -0.270 | -4.569 | -0.009 | -3.445 | 0.5488 |
| | $E_2$ | -0.297 | 0.687 | 0.012 | 0.0001 | -0.289 | 0.884 | **-10.983** | -0.018 | -1.053 | 11.766 | 0.010 | 0.058 | 0.7578 |
| Extraction at 12 months (%) | $E_1$ | -0.512 | 0.154 | 0.003 | 0.068 | 0.310 | -0.138 | 0.330 | **0.056** | 0.002 | -0.102 | -0.015 | -0.077 | 0.0799 |
| | $E_2$ | 0.184 | -0.169 | -0.014 | 0.0001 | 0.037 | 0.217 | -3.545 | **-0.058** | -0.532 | 4.059 | -0.0001 | 0.011 | 0.1887 |
| Purity at 12months (%) | $E_1$ | 1.029 | -5.808 | 0.001 | 0.190 | 4.702 | 0.290 | 6.235 | -0.000 | **-0.498** | -3.287 | -0.006 | -2.479 | 0.3673 |
| | $E_2$ | -0.024 | 0.252 | 0.010 | 0.0001 | -0.133 | 0.187 | -6.993 | -0.018 | **-1.654** | 8.970 | 0.009 | 0.029 | 0.6359 |
| CCS at 12months (%) | $E_1$ | 2.299 | -10.832 | -0.019 | 0.263 | 8.424 | -2.266 | 11.234 | 0.001 | -0.0351 | **4.669** | -0.009 | -3.521 | 0.5528 |
| | $E_2$ | -0.262 | 0.646 | 0.012 | 0.0001 | -0.277 | 0.794 | 10.839 | -0.019 | 1.244 | **11.922** | 0.011 | 0.039 | 0.7817 |
| Fibre content at harvest (%) | $E_1$ | -0.806 | 1.543 | 0.039 | 0.052 | -0.762 | -0.263 | 1.130 | 0.008 | -0.031 | -0.454 | **-0.100** | -0.342 | 0.0134 |
| | $E_2$ | -0.217 | 0.367 | 0.027 | 0.000 | -0.137 | 0.263 | -4.017 | 0.0001 | -0.546 | 4.542 | **0.029** | 0.015 | 0.3277 |
| Pol in cane at harvest (%) | $E_1$ | 2.299 | -10.833 | -0.019 | 0.263 | 8.424 | -2.266 | 11.233 | 0.001 | -0.351 | -4.669 | -0.009 | **-3.521** | 0.5528 |
| | $E_2$ | -0.251 | 0.585 | 0.013 | 0.0001 | -0.247 | 0.638 | -0.8639 | -0.013 | 0.986 | 9.479 | 0.009 | **0.049** | 0.6372 |

*Unexplained variation at phenotypic level under $E_1$ = 0.15 Unexplained variation at phenotypic level under $E_2$ = 0.17*

**Table 3. Estimates of direct and indirect effects of different Quality traits of sugarcane genotypes on commercial cane sugar (CCS) (t/ha) at genotypic level under normal ($E_1$) and water stress ($E_2$) environments**

| Traits | Env. | Brix at 10 months (%) | Pol in juice at 10 months (%) | Extraction at 10 months (%) | Purity at 10 months (%) | CCS at 10 months (%) | Brix at 12 months (%) | Pol in juice at 12 months (%) | Extraction at 12 months (%) | Purity at 12 months (%) | CCS at 12 months (%) | Fibre content at harvest (%) | Pol in cane at harvest (%) | Correlati-on with CCS (t/ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Brix at 10 months (%) | $E_1$ | **-8.123** | -2.219 | -0.097 | 0.166 | 10.183 | -2.673 | 1.506 | -0.019 | -0.561 | 14.503 | 0.030 | -12.503 | 0.1919 |
| | $E_2$ | **2.938** | 1.202 | 0.057 | 0.113 | -4.054 | -1.446 | 2.290 | 0.219 | -0.016 | -0.763 | -0.1252 | 0.1172 | 0.3354 |
| Pol in juice at 10 months (%) | $E_1$ | -7.896 | **-2.283** | -0.069 | -0.458 | 10.750 | -3.529 | 2.225 | -0.003 | -1.442 | 22.266 | 0.021 | -19.195 | 0.3853 |
| | $E_2$ | 2.799 | **1.262** | 0.073 | 0.586 | -4.463 | -1.692 | 3.182 | 0.007 | -0.116 | -1.136 | -0.134 | 0.165 | 0.5324 |
| Extraction at 10 months (%) | $E_1$ | 2.055 | 0.412 | **0.383** | -0.785 | -1.560 | 1.648 | -1.239 | -0.039 | 1.271 | -13.026 | -0.879 | 11.233 | 0.2652 |
| | $E_2$ | 0.829 | 0.450 | **0.204** | 0.507 | -1.720 | -0.359 | 0.700 | 0.032 | -0.024 | -0.254 | -0.096 | 0.052 | 0.3186 |
| Purity at 10 months (%) | $E_1$ | 0.514 | -0.397 | 0.114 | **-2.635** | 2.997 | -4.022 | 3.231 | 0.061 | -3.721 | 34.538 | -0.038 | -29.767 | 0.8757 |
| | $E_2$ | 0.210 | 0.467 | 0.065 | **1.584** | -2.249 | -1.170 | 3.415 | -0.040 | 0.315 | -1.375 | -0.064 | 0.185 | 0.7121 |
| CCS at 10 months (%) | $E_1$ | -7.651 | -2.270 | -0.055 | -0.730 | **10.811** | -3.848 | 2.508 | 0.003 | -1.811 | 25.353 | 0.0164 | -21.858 | 0.4658 |
| | $E_2$ | 2.641 | 1.249 | 0.077 | 0.790 | **-4.509** | -1.752 | 3.497 | 0.0008 | -0.160 | -1.275 | -1.134 | 0.182 | 0.6082 |
| Brix at 12 months (%) | $E_1$ | -3.010 | -1.117 | -0.087 | -1.469 | 5.767 | **-7.215** | 3.538 | 0.026 | -0.433 | 32.274 | -0.053 | -27.829 | 0.3905 |
| | $E_2$ | 1.614 | 0.811 | 0.027 | 0.704 | -3.001 | **-2.632** | 4.940 | -0.014 | -0.193 | -1.764 | -0.123 | 0.243 | 0.6117 |
| Pol in juice at 12 months (%) | $E_1$ | -3.034 | -1.260 | -0.118 | -2.112 | 6.727 | -6.333 | **4.030** | 0.015 | -2.878 | 40.472 | -0.051 | -34.897 | 0.5597 |
| | $E_2$ | 1.255 | 0.749 | 0.026 | 1.009 | -2.942 | -2.426 | **5.361** | -0.036 | -0.332 | -2.018 | -0.137 | 0.267 | 0.7766 |
| Extraction at 12 months (%) | $E_1$ | 1.249 | 0.067 | -0.118 | -1.282 | 0.298 | -1.509 | 0.484 | **0.126** | 0.473 | 3.320 | -0.486 | -2.863 | 0.1984 |
| | $E_2$ | 0.659 | 0.100 | -0.068 | 0.659 | 0.036 | -0.394 | 1.973 | **-0.097** | -0.272 | -0.862 | -0.047 | 0.078 | 0.2447 |
| Purity at 12 months (%) | $E_1$ | -0.8716 | -0.6289 | -0.093 | -1.873 | 3.741 | -0.597 | 2.216 | -0.011 | **-5.235** | 27.925 | -0.160 | -24.064 | 0.4906 |
| | $E_2$ | 0.111 | 0.332 | 0.011 | 1.129 | -1.630 | -1.151 | 4.030 | -0.060 | **-0.442** | -1.678 | -0.109 | 0.210 | 0.7526 |
| CCS at 12 months (%) | $E_1$ | -2.870 | -1.238 | -0.121 | -2.217 | 6.678 | -5.673 | 3.974 | 0.010 | -3.562 | **13.043** | -0.047 | -35.387 | 0.5866 |
| | $E_2$ | 1.103 | 0.705 | 0.025 | 1.071 | -2.829 | -2.285 | 5.322 | -0.041 | -0.365 | **-2.033** | -0.1372 | 0.266 | 0.8034 |
| Fibre content at harvest (%) | $E_1$ | 1.085 | 0.210 | 0.147 | -0.438 | -0.772 | -1.685 | 0.895 | 0.026 | -0.365 | 8.470 | **-0.229** | -7.301 | 0.0426 |
| | $E_2$ | 1.418 | 0.652 | 0.075 | 0.394 | -2.329 | -1.251 | 2.838 | -0.017 | -0.187 | -1.075 | **0.259** | 0.155 | 0.4145 |
| Pol in cane at harvest (%) | $E_1$ | -2.870 | -1.238 | -0.121 | -2.216 | 6.677 | -5.674 | 3.975 | 0.010 | -3.560 | 41.041 | -0.474 | **11.389** | 0.5866 |
| | $E_2$ | 1.327 | 0.804 | 0.041 | 1.132 | -3.174 | -2.467 | 5.526 | -0.029 | -0.358 | -2.087 | -0.155 | **0.259** | 0.8173 |

*Unexplained variation at genotypic level under $E_1$ = 0.18, Unexplained variation at genotypic level under $E_2$ = 0.19* leading to the simultaneous improvement in the remaining quality traits and sugar yield. Also results shown by Tena [20] indicated that cane yield had a strong positive and highly significant correlation with millable cane number, single cane weight, stalk height and sugar yield. Similarly, at phenotypic level sugar yield (t/ha) had significant positive correlation with pol (%), purity (%), CCS (%) at 10 months and brix (%), pol (%), purity (%), CCS (%) and pol (%) in cane at harvest under both normal ($E_1$) as well as water stressed ($E_2$) conditions (Table 1). Though efficiency of selection in any breeding programme mainly depends upon the knowledge of association of characters yet they indicate the nature of association among the traits, but path coefficient analysis splits the correlation values into direct and indirect effects so as to measure the relative importance of causal factors involved. As many variables are included in correlation studies, the indirect effects of other variable become confounded. In such a situation, path coefficient analysis is useful in finding out direct and indirect causes of associations and allows a precise perception of specific forces acting to produce a given correlation [21-22] and relative importance of each causal factor also becomes evident [23].

In present investigation, the direct and indirect effects of different traits on sugar yield (t/ha) at phenotypic level were worked out for both normal ($E_1$) and water stressed ($E_2$) conditions (Table 2). Perusal of data revealed that under normal ($E_1$) environment among different quality traits CCS (%) at 10 months had the highest (17.944) direct effect on sugar yield (t/ha) followed by pol (%) in juice at 12 months (11.480), brix (%) at 10 months (8.735), commercial cane sugar (%) at 12 months (4.669), purity (%) at 10 months (0.683), juice extraction percent at 10 months (0.163). Thippeswamy and Tena [19-20] also reported similar trends of direct effects of quality traits on sugar yield. Under water stress ($E_2$) environment, CCS (%) (11.922) had maximum direct effect on CCS (t/ha) followed by pol (%) in juice at 10 months (1.351), brix (%) at 12 months (1.010), juice extraction (%) at 10 months (0.084) and pol (%) cane at harvest (0.049).

For indirect effects of quality traits, under water stress ($E_2$) conditions, brix (%) at 10 months had negative direct affect on commercial cane sugar (t/ha) but it had a positive indirect effect via pol (%) at 10 months. CCS (%) at 10 months had negative direct effect but had positive indirect effect via CCS (%) at 12 months. Similarly, brix (%) at 12 months, pol (%) at 12 months, juice extraction (%) at 12 months, purity (%), fibre (%) at harvest and pol (%) cane at harvest had a positive indirect effect on commercial cane sugar (t/ha) via CCS (%) at 12 months after planting. These findings are in agreement with Singh [24] and Sanghera [2] for positive indirect effect of different quality traits on CCS (t/ha).

A perusal of direct and indirect effects at genotypic level (Table 3) quality traits CCS (%) at 12 months (13.043) had maximum positive direct effect on CCS (t/ha) under normal ($E_1$) conditions followed by pol (%) cane at harvest (11.389), pol (%) in juice at 12 months (4.030), juice extraction (%) at 10 months and 12 months (0.383 and 0.126, respectively) and fibre (%) at harvest had negative direct effect. Under water stress ($E_2$) conditions, pol (%) in juice at 12 months (5.361) had maximum direct effect on CCS (t/ha) followed by brix (%) at 10 months (2.938), purity (%) at 10 months (1.584), pol (%) in juice at 10 months (1.262), fibre (%) at harvest (0.259), pol (%) cane percentage at harvest (0.259) and juice extraction (%) at 10 months (0.204). In case of indirect effects, under $E_2$ environment brix (%) at 10 months had positive indirect effect on CCS (t/ha) via all quality traits. These results are in conformity with Tygai [25]. Similarly pol (%) in juice at 10 months had also positive indirect effect via all the quality. Shahzad [26] reported that highest direct effect on sugar recovery was shown by purity, followed by brix (%) which confirms that these traits could contribute more towards an increase of sugar recovery. Path coefficient results showed the amount of contribution either directly or indirectly and also the percentage contribution of each parameter to the sugar yield.

## 4. CONCLUSIONS

Under water stress conditions, pol (%) in juice at 12 months had maximum direct effect on ccs (t/ha) followed by brix (%) at 10 months, purity (%) at 10 months, pol (%) in juice at 10 months, fibre (%) at harvest, pol (%) cane percentage at harvest and juice extraction (%) at 10 months. Present study revealed that traits like brix (%) 10 months, pol (%) in juice, pol (%) cane and juice extraction (%) be emphasized for sugar yield improvement under water stress conditions.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## REFERENCES


1. Malik SS, Tomar BS. Impact of rainfall and temperature on sugarcane quality. Agri Sci Digest. 2003;23(1):50-52.
2. Sanghera GS, Tyagi V, Kumar R, Thind KS. Genetic variability for cane yield, earliness and quality traits in sugarcane under subtropical region of India. Int J Current Res. 2014;6(8):7763-65.
3. Silva MDA, Jifon JL, Silva JAGD, Santos CMD. Relationships between physiological traits and productivity of sugarcane in response to water deficit. J Agri Sci. 2014;152(1):104-18.
4. Vinocur B, Altman A. Recent advances in engineering plant tolerance to abiotic stress: achievements and limitations. Curr Opin Biotech. 2005;16:123-32.
5. Das R, Ghoshal SK, Ray BR, Mazumdar D. Study of correlation and path analysis in relation to cane and sugar yield of sugarcane. Sugar Tech. 2007;9:293-99.
6. Cardozo NP, Sentelhas PC. Climatic effects on sugarcane ripening under the influence of cultivars and crop age. Sci Agric. 2013;70(6):449-56.
7. Chen JCP, Chou Chung-Chi. Cane sugar handbook: a manual for cane sugar manufacturers and their chemists. John Wiley and Sons, 1993; 1090.
8. Thangavelu S, Rao CK. Comparison of Rapipol extractor and cutex cane shredder methods for direct determination of fibre in Saccharum clones. Proc Ann Conv Sug Tech Assoc India. 1982;46:15-21.
9. Chen JCP. Cane Sugar Hand Book. 11th edition, A Wiley Inter Science Publication. John Wiley Sons, New York. 1985;947.
10. Fisher RA. The design of experiments. Oliver and Boyd, Edinburg; 1935.
11. Cheema HS, Singh B. A user’s manual to CPCS- 1: A computer programme package for the analysis of commonly used experimental designs, PAU, Ludhiana; 1990.
12. Al-Jibouri HA, Millar PA, Robinson. Genotypic and environmental variances and co-variance in an upland cotton cross of interspecific origin. J Agron. 1958;50:633-37.
13. Dewey DR, Lu KH. A correlation and path-coefficient analysis of components of crested wheatgrass seed production. Agron J. 1959;51:515-18.
14. Singh B. A users' manual to MVM: A computer programs package for the analysis of commonly used multivariate methods, PAU, Ludhiana; 1993.
15. Punia MS. Studies on variability, heritability and genetic advance of some quality attributes in sugarcane. Ind Sugar. 1982;31:911-14.
16. Khan IA, Khatari A, Siddiqui MA, Nizamani GS, Raza S. Performance of promising sugarcane clones for yield and quality in different ecological zones of Sindhi. Pak J Bot. 2004;36(1):83-92.
17. Kumar S, Singh PK, Singh J, Kumar S. Genetic variability, heritability, genetic advance and correlations in sugarcane under moisture deficit condition. Ind J Sugarcane Tech. 2001;16:32-35.
18. Sreekumar K, Jessy Kuriakose M, Mathew T, Alexander D, Santhakumari S. Variability, heritability and correlation studies on yield and quality characters of sugarcane. Ind Sugar. 1994;44:243-49.
19. Thippeswamy S, Kajjidoni ST, Salimath PM, Goud JV. Correlation and Path Analysis for Cane Yield, Juice Quality and Their Component Traits in Sugarcane. Sugar Tech. 2003;5:65-72.
20. Tena E, Mekbib F, Ayana A. Correlation and path coefficient analyses in sugarcane genotypes of Ethiopia. Am J Pl Sci. 2016;7:1490-97.
21. Mali SC, Patel A, Patel DU, Patel CL. Variability, correlation, path analysis and genetic divergence in sugarcane (*Saccharum* spp.) Research on Crops. 2010;11:497-504.
22. Sanghera GS, Tyagi V, Kumar R, Thind KS, Sharma B. Genetic variability, association and their dissection through path analysis for cane yield and its component traits in early maturing

sugarcane clones. J Sci. 2015;5(1):28-34.
23. Khan IA, Bibi S, Yasmin S, Khatri A, Seema N, Abro SA. Correlation studies of agronomic traits for higher sugar yield in sugarcane. Pak J Bot. 2012;44(3):969-71.
24. Singh RK, Singh SP, Singh SB. Correlation and path analysis in sugarcane ratoon. Sugar Tech. 2005;7:176-78.
25. Tyagi VK, Sharma S, Bhardwaj SB. Pattern of association among cane yield, sugar yield and their components in sugarcane (*Saccharum officinarum* L.). J Agri Res. 2012;50:29-38.
26. Shahzad S, Shokat S, Fiaz N, Hameed A. Impact of yield and quality-related traits of sugarcane on sugar recovery. J Crop Sci Biotech. 2017;20:1-7.



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