Long-term response of dragon fruit \((Hylocereus undatus)\) to transformed rooting zone of a shallow soil improving yield, storage quality and profitability in a drought prone semi-arid agro-ecosystem

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**Abstract**

Agricultural crops especially fruit trees are constrained by edaphic stresses in shallow soils with low water retention and poor fertility. Therefore, interventions of shifting to trench planting for better root anchorage and replacing the filling soil were evaluated for 8 years in dragon fruit \((Hylocereus undatus)\) cultivated in Deccan Plateau of peninsular India. When averaged for last 5-years, 44 % higher fruit yield \((18.2 \pm 1.0 \ \text{Mg ha}^{-1})\) was harvested from trees planted in trenches filled with 1:1 mixture \((T\text{-mixed})\) of native soil \((loamy sand with 26.7 % stones (>2mm), field capacity, FC 0.20 \text{ cm}^3 \text{ cm}^{-1}, \text{ organic carbon, OC 0.17 \%; Av-N 54.6 kg ha}^{-1})\) and a black soil \((clay 54.4 \%; FC 0.42 \text{ cm}^3 \text{ cm}^{-1}; \text{ OC 0.70 \%; Av-N 157.1 kg ha}^{-1})\) than the recommended pit planting \((12.4 \pm 1.2 \ \text{Mg ha}^{-1})\). Improvements in fruit yields with trenches filled with black \((T\text{-black})\) and native \((T\text{-native})\) soil were 32 and 13 %, respectively. Yield losses \((\text{total– marketable yield})\) were reduced by 40, 20 and 18 % over pit method with \(T\text{-mixed}, T\text{-black}\) and \(T\text{-native}\) soil, respectively. Marketable quality attributes like fruit weight, fruit size metrics and pulp/peel content were further improved under \(T\text{-mixed}\) soil. Accumulation of total soluble solids \((\text{TSS})\), sugar content, phenolic and flavonoid compounds were higher in fruits from \(T\text{-native}\) soil. During storage, fruits from \(T\text{-native}\) soil and pit planting exhibited minimum physiological weight loss and retained more firmness, TSS, sugars, titratable acidity, phenolic-flavonoids contents, FARP and DPPH activities. \(T\text{-mixed}\) soil provided better hydrozone and nutrients for resilience of fruit plants while protecting from aeration problems envisaged in poorly drained black soils. With B:Ca ratio \((1.85)\) and lower payback period \((4\text{-years})\), \(T\text{-mixed}\) soil showed superior economic viability. Therefore, soil management module of planting in trenches filled-in with mixture of native and black soils can be recommended to boost productivity of fruits from shallow soils under water scarce degraded regions without penalising agro-ecosystem.

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1. Introduction

Climate change accompanied by multitude of abiotic and biotic stresses is posing serious threats to agriculture, natural resources and food production system worldwide (Minhas et al., 2017; Teshome et al., 2020). The situation is likely to exacerbate with increased frequency of aberrant weather events of varying intensity (Chhogyel et al., 2020). As a consequence, the edaphic stresses are expected to multiply to further degrade the soils, while urbanisation and other anthropogenic activities are already encroaching upon the cultivated land (NAAS, 2017). Globally, about 2 billion ha land is affected by degradation resulting in edaphic stresses to a degree sufficient to reduce their productivity. Besides, almost 5.8 million ha (Mha) of world usable land gets degraded annually owing to deforestation, overgrazing and industrial activities possess a severe impact to the environment and agroecosystem (FAO, 2011; Parada et al., 2021). The key chemical stresses, which presently threaten the agricultural productivity in about 35 % of the geographical area of India (Maji et al., 2010; Minhas and Reddy, 2017) include emerging nutrient deficiencies with mining (8–10 million Mg of NPK annually) along with acidity \((\text{pH } < 5.5)\)
in 17.93 M ha), salinity (6.73 M ha) and soil contaminants while physical stresses include severe soil erosionity (82.47 M ha and wind 12.40 M ha), shallow soils (26.4 M ha), soil hardening (21.4 M ha) and low water holding capacity (13.75 M ha). Though a daunting task, the emanating newer tools especially in the areas of conservation agriculture, precision irrigation technologies, biotechnology and omic sciences are opening up new opportunities for tackling these stresses (Minhas et al., 2017). However, the shallow and low fertility soils especially in the water scarce and drought prone agro-ecologies of Peninsular India have so far received comparatively lesser attention and thus these lag far behind in terms of crop diversification, production and agricultural market economization (Mandal et al., 2012; Minhas et al., 2015a). Following the neighbouring farmers of fertile areas and with the zeal to get higher economic gains, farmers are increasingly resorting to the orchards under such hostile environment. Nevertheless, the productivity potential of shallow soils continues to be low and these are frequently affected by droughts during which a large scale damage even mortality of horticulture orchards is visualized. To overcome the edaphic constraints, reduce hostile environmental impacts and to create favourable niches in the ambience where roots are located, both on-site soil and water conservation technologies like trenching, contour/strip planting, graded furrows/ridges are being advocated to enhance crop/tree growth while the off-site techniques include storage of run-off, transport of canal/drain water through multi-stage-pumping or water tankers and switching to drip irrigation (Minhas et al., 2015b). The other possible alternative to overcome water deficits and nutritional constraints in shallow soils is shift to trench rather than recommended pit planting for better anchorage by enlarging volumes of soils for root development and transform the low water and nutrient retentive native soil with fertile and high water holding capacity soil when refilling these trenches. The crop-based interventions demand for identification of native, non-conventional and exotic field and fruit crops, species and genotypes, which can be diversely grown as an alternative remunerative crop in such underutilised harsh ecosystems (Hegde, 2008; Hussain et al., 2020). Among the exotic species, dragon fruit, a tropical cactus vine (xerophytes) is highly tolerant to abiotic stress environment and resilient to all pest and diseases (Abirami et al., 2021; Sinha et al., 2018). Recently, it has emerged as super crop with great potential of marketing and numerous cultivation benefits e.g. low soil–water-nutrients demand, least care for establishment and maintenance of orchards; multiple fruit harvestings per annum; persistent higher fruit yields (>20 years) and high net returns (Trivedi et al., 2020; Niranjan et al., 2020). Its fruit is rich in functional, antiradical and antiproliferative activities and nutraceuticals properties e.g. vitamins, minerals, complex carbohydrates, antioxidants and dietary fibres supporting its marketability among the health-conscious consumers (Le Bellec et al., 2006; Wakchaure et al., 2021). Owing to peculiar exotic appearance and organoleptic qualities, its demand has recently multiplied among majority of urban and rural population (Perwee et al., 2018). Moreover, it has got adaptability to grow in diverse ecological conditions (Blom-Zandstra et al., 2017; Goenaga et al., 2020). Thereby, the growers, particularly in the western and southern parts of India have now started its large scale farming for commercial production (Kuranakaran et al., 2019). With the shallow fibrous and aerial rooting system (<40 cm), it rapidly assimilates even smallest quantity of water and nutrients and hence not much peculiar for specific soil requirements (Perwee et al., 2018). Overall it is inferred that dragon fruit is utilized for both consumption and processing, which indicate towards its ability to provide high economic returns with relatively minimal inputs. Possibilities are that dragon fruit can become one of the remunerative crops, when cultivated even in water scarce degraded land regions. Since this is slightly newer crop for such environmental conditions, proper understanding of managing its plantation seems essential. Moreover, issues related to its adaptation to water deficits, consumer acceptability, shelf-life, market opportunity and economic viability mainly cost and returns, benefit cost ratio and payback period must be critically assessed before recommending for large scale cultivation. Keeping above view, the hypothesis is that better hydrozone and nutrients should provide for resilience to plants when confronted with prolonged dry periods during drought environments. Therefore the first objective of present investigation was to evaluate effectiveness and viability of trench planting and various filling mixtures on long-term basis. Alternatively, production potential and economic viability of dragon fruit were evaluated in terms of its marketable and total yields on shallow basaltic soils as such and with transformed soil of rooting zone. Consequently, another objective was to assess the quality attributes of fruits along with their storage behaviour for prolonging the shelf-life.

2. Material and methods

2.1. Location and weather conditions

The experiment was conducted for eight consecutive years (2013–2020) at Model Research Farm of ICAR-National Institute of Abiotic Stress Management, located at Baramati in Pune district of Maharashtra state, India (18°09′ 30.62″N, 74°30′ 00.08′E, 570 M.A.S.L). Experimental site falls into agro-ecological region Deccan Plateau, hot and semi-arid climate (AER-6) and agroclimatic zone AZ-95 which is water scarcity zone of Maharashtra (Fig. 1). The area is highly susceptible to drought and soils are mainly characterised by degraded shallow murrum soils (0.1–0.3 m depth) as originated from parental basaltic rocks. The long term average annual precipitation, average annual temperature, annual Class A open pan evaporation (Pan-E) and annual PAR (photo-synthetically active radiation) are 584.1 mm, 26.3 °C, 2220.1 mm and 201 W m⁻², respectively. Precipitation is erratically distributed and mainly restricted to the south–west (70 %, June–September) and the retreating monsoon (21 %, October–December). Some of the weather parameters during six consecutive fruit seasons (2015–2020) of dragon fruit were recorded at NIASM’s automatic weather station (AWS) included in Table 1. The seasonal averages of monthly mean, maximum and minimum temperatures were 25.8, 31.1, and 20.6 °C, respectively. The monthly averages of daily relative humidity, bright sunshine and wind speed during seasons were reported to be 71.8 %, 5 h and 7.7 km h⁻¹, respectively. During initial period of dragon fruit establishment in 2013–14, the average monthly temperatures, relative humidity, rainfall, wind speed and sunshine were 25.5 °C, 59.5 %, 641.6 mm, 7.2 km h⁻¹ and 6.7 h, respectively.

2.2. Treatment details, experimental design and cultural practices

The present study comprised two sets of experiments (i) on modes of dragon fruit orchard establishment and (ii) biochemical analysis and post–harvest storage of its fruits. The field site chosen for establishing experimental orchard was rocky basaltic terrain of relatively steeper slope (4 %) with little vegetation. It was initially ripped and chained repeatedly (2–3 times) by heavy dozer (Model D355, Irrigation Department, Maharashtra state) with subsequent micro-blasting of hard patches until the plots/terrace got uniformly levelled. Afterwards, locally available spent wash (a by-product sugarcane industry) was applied for further pulverization of gravelly murrum. As virgin soil was porous, stony (26.7 % > 2 mm), low in fertility (Organic carbon (OC) 0.07 %; Av-P
0.5 kg ha\(^{-1}\)) and poor in water retention capacity; heavy amount of spent mushroom substrate (250 m\(^3\)/ha) were added.

The experimental field (0.33 ha area) was divided into five blocks (31.5 m \(\times\) 18 m). Nine trenches (15 m length \(\times\) 1 m breadth \(\times\) 0.5 m depth) were dug in each block keeping the spacing of 3.5 m apart. Another nine lines of pits each constituting three pits (1 m \(\times\) 1 m \(\times\) 0.5) at 3 m apart were dug in parallel to trenches in each block. Initial plan was to establish 20 treatments comprising of pit-trench soils and irrigation levels in randomised block design. However latter could not be established due to scarce and interrupted irrigation water supplies. The filling mixtures in trenches consisted of either i) original native soil (T-Native, loamy sand; clay 10.3 %; mostly murrum with 26.7 % stones (>2mm), field capacity (FC) 0.20 cm\(^3\)/cm\(^3\); organic carbon (OC) 0.17 %; Av-N 54.6 kg ha\(^{-1}\); Av-P 1.3 kg ha\(^{-1}\); and ii) black soil transported from adjoining fields (T-Black, clay 54.4 %; FC 0.42 cm\(^3\)/cm\(^3\); OC 0.70 %; Av-N 157.1 kg ha\(^{-1}\); Av-P 6.3 kg ha\(^{-1}\)) and iii) mixture of the two soils (T-mixed soil; 1:1 Black: Native). The physico-chemical properties of soil filling mixtures were determined using the standard methods (Table 2). Pits were filled with native soil, as a common practice adopted by farmers in the regions (control) for comparing with trench soils. Layout plan is shown in Fig. 2. Concrete posts were fixed in filled-in pits and trenches at a spacing of 3 m and fresh stem segments of 20–25 cm mature cuttings of dragon fruit (Hylocereus undatus) were transplanted into 6–8 cm soil depth around these concrete posts on 6 December 2013. Prior to transplanting, each segment was slanted cut (2–3 cm) at the base and kept for 4–6 h in the shed for drying the oozing latex. Thereafter, all the cut segments were treated with fungicide (1500 ppm carbendazim) and 5000 ppm Indole 3-butyric acid (IBA) to prevent soil-borne diseases and improve shoot and root development, respectively. The height of concrete posts was 2 m and buried 0.40 m in soil to support the load of both plant canopy and standard trellis system during growth and after establishment of orchard. Required quantity of water (2–4 L plant\(^{-1}\)) was applied twice a week through drip irrigation. In extreme water scarcity conditions of summer season (March-May), minimum two water saving irrigations with 15 days interval were applied through tan-

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### Table 1

| Fruiting season | T\(_{\text{max}}\) (°C) | T\(_{\text{min}}\) (°C) | Mean RH (%) |
|-----------------|-----------------|-----------------|-------------|
|                 | 2015 2016 2017 2018 2019 2020 | 2015 2016 2017 2018 2019 2020 | 2015 2016 2017 2018 2019 2020 |
| June            | 32.6 32.8 33.0 32.9 35.6 32.3 | 21.9 22.7 22.8 22.9 23.7 22.3 | 70.8 66.8 72.8 69.6 61.1 73.0 |
| July            | 31.4 29.3 30.5 29.4 30.3 30.6 | 21.9 21.8 22.0 22.0 22.2 22.3 | 66.7 78.0 73.3 77.4 79.7 78.9 |
| August          | 31.4 30.1 30.4 29.5 30.0 29.6 | 20.4 21.4 21.3 21.4 21.3 21.6 | 68.2 71.6 75.4 77.7 77.3 80.4 |
| September       | 32.0 29.5 31.0 32.1 30.6 31.4 | 21.0 20.5 21.5 20.3 21.5 22.0 | 67.2 74.8 75.3 68.8 76.3 77.2 |
| October         | 33.1 30.9 32.3 33.1 30.0 31.3 | 20.4 18.9 20.5 19.5 20.9 20.9 | 60.1 64.4 67.9 57.8 78.3 73.9 |
| November        | – 30.2 30.6 31.4 30.0 30.9 | – 12.9 15.6 16.6 18.2 17.4 | – 49.9 59.1 59.3 70.3 63.0 |
| Mean/Total      | 32.1 30.5 31.3 31.4 31.1 31.0 | 21.1 19.7 20.6 20.4 21.3 21.1 | 66.6 67.6 70.6 68.4 73.8 74.4 |

| Fruiting season | Rainfall (mm) | CPE (mm) | BSS (h) |
|-----------------|-----------------|-----------------|--------|
|                 | 2015 2016 2017 2018 2019 2020 | 2015 2016 2017 2018 2019 2020 | 2015 2016 2017 2018 2019 2020 |
| June            | 49.7 121.6 182.1 143.6 36.4 158 | 171.3 196.3 169.7 165.7 188.5 248.1 | 152.9 4.0 3.7 5.3 3.2 4.7 5.1 |
| July            | 26.1 49.2 49.2 32.6 162.6 141 | 202.8 113.5 176.5 152.1 126.6 119.3 | 3.6 1.5 3.5 2.1 3.2 3.7 |
| August          | 4.6 39.6 108.5 20.5 19.6 78.6 | 184.0 157 145.9 141.2 140.1 107.6 | 4.8 4.5 4 2.5 4.4 2.7 |
| September       | 120.7 211 306 36.4 162.6 273.8 | 161.2 124.8 115 179.8 124.4 122.4 | 5.6 3.3 5.3 6.6 3.6 5.2 |
| October         | 62.8 48.2 109.4 80.8 332.4 283 | 164.6 146.1 142.8 179.5 109.7 118.5 | 7.4 7.2 6.7 8.2 5.2 5.8 |
| November        | – 0 2.8 13.3 25.6 0 | – 132.1 142.2 134.6 101.3 141.3 | – 8.9 8.1 8.0 7.5 7.9 |
| Mean/Total      | 263.9 469.6 758 327.2 739.2 936.4 | 883.9 869.7 892.1 975.7 850.2 762 | 5.1 4.9 5.5 5.1 4.8 5.1 |
ker for the survival of plants. At the time of transplanting, a basal
dose of 10–15 kg FYM and 100 g SSP was applied to each plant.
During the initial two years, 300 g N, 200 g P and K per plant
was applied. Thereafter when the orchard got well-established,
recommended doses of 540 g N, 720 g P and 300 g K per plant
were applied in four equal splits with interval of 3 months. The fruits
were harvested manually using pruner shear at physiological
maturity i.e. after skin colour changes from bright green to red or
pinkish. This required 6–8 pickings between July-November.

2.3. Measurement of fruit yield, fruit losses and physical quality traits

Total fruit yield (TFY, Mg ha$^{-1}$) of freshly harvested dragon
fruits was recorded on fresh weight basis (f.w.b). Marketable fruit
yield (MFY, Mg ha$^{-1}$) was computed after discarding inferior, dis-
eased and infected fruits by insects and birds etc. from each plot
(pit/trench). Other attributes viz., proportions of red skin, white
flesh colour, oblong shape and firmness of fruits were also consid-
ered for selection. After each harvesting, TFY, MFY and discarded
fruits yield were recorded and later cumulated for total yield. The mean fruit diameter (D$_{gm}$), shape index, fruit weight, fruit pulp
and peel weight were monitored from the 30 random fruit samples
collected from each plot at 3rd and 4th harvesting. The mean diam-
eter (D$_{gm}$) and shape index were calculated by measuring longitu-
dinal, transverse diameters and thickness of fruits using digital
vernier calliper as described by Magalhães et al. (2019) and Park
et al. (2013). The fruit pith and peels were detached and peels were
weighed (g) was using laboratory weighing scale (Mlab-WB-40B).
The pulp weight was calculated by subtracting of peel and seed
weight from total fruit weight.

2.4. Analysis of biochemical quality and changes during storage

Uniform samples were drawn from marketable fruits of 3rd and
4th harvesting for biochemical and storage quality analyses. These
were washed using tap water and allowed to dry in laboratory at
ambient conditions. These were then stored for 28 days under
standard conditions i.e. temperatures ($8$ °C) and relative humidity

| Soil properties | Native soil (sandy loam soil) | Black soil (clay soil) | Mix Soil (sandy clay soil) | Method |
|-----------------|------------------------------|-----------------------|----------------------------|--------|
| Gravel (%) > 2 mm | 26.7 ± 4.6                  | 3.3 ± 0.5             | 16.3 ± 2.8                 | International pipette method (Beretta et al., 2014) |
| Sand (%)        | 48.0 ± 6.7                   | 22.2 ± 1.3            | 32.3 ± 2.2                 | Elico conductivity bridge (1:2.5 soil; water suspension) (Jackson, 2005) |
| Silt (%)        | 15.1 ± 2.9                   | 20.0 ± 0.7            | 17.7 ± 1.4                 | Glass electrode pH meter (Piper, 1966) |
| Clay (%)        | 10.3 ± 1.6                   | 54.4 ± 1.0            | 33.7 ± 1.7                 | Alkaline permangante method (Subbiah and Asija, 1956) |
| EC(dS m$^{-1}$) | 0.18 ± 0.01                  | 0.24 ± 0.02           | 0.19 ± 0.02                | Olsen’s method (Olsen et al., 1954) |
| Organic Carbon | 0.17 ± 0.02                  | 0.70 ± 0.02           | 0.48 ± 0.04                | Flame photometric method (Jackson, 1967) |
| Available N (kg ha$^{-1}$) | 54.6 ± 1.9                 | 157.1 ± 12.2          | 103.9 ± 6.3                | Pressure Extractor (Dane and Hopmans, 2002) |
| Available P(kg ha$^{-1}$) | 1.3 ± 0.6                   | 6.3 ± 1.7             | 4.7 ± 1.3                  | Olsen’s method (Olsen et al., 1954) |
| Available K (kg ha$^{-1}$) | 76.1 ± 1.6                  | 143.8 ± 13.4          | 108.7 ± 2.5                | Flame photometric method (Jackson, 1967) |
| F. C. (cm$^3$ cm$^{-3}$) | 0.20 ± 0.002                | 0.42 ± 0.002          | 0.33 ± 0.003               | Pressure Extractor (Dane and Hopmans, 2002) |
| PWP (%)        | 10.0 ± 0.08                  | 17.3 ± 0.08           | 13.7 ± 0.14                | Volumetric method (Rai et al., 2017) |
| A.W. (%)       | 13.7 ± 0.10                  | 24.9 ± 0.12           | 19.4 ± 0.20                | Volumetric method (Rai et al., 2017) |
| B. D. (g/cc)   | 1.36 ± 0.01                  | 1.25 ± 0.01           | 1.32 ± 0.02                | Volumetric method (Rai et al., 2017) |

Fig. 2. Details of experimental layout and trench (T-Native, T-Mixed, T-Black) and pit (P-control) soil treatments for dragon fruit plantation.
(60–70 %) in three batches using controlled storage chambers (Model: DR36VL, R – 134A refrigerant, Percival Scientific, USA).

The sampled fruits were analysed for biochemical quality characteristics and antioxidant activity (AOA) initially and at 4, 8, 12, 16, 20, 24 and 28 days of storage. For this, fruits were peeled manually and the seeds and pulp was also separated. The pulp and peel material was sliced into smaller cubes (~5 mm) and blended for homogeneity. Total soluble solids (TSS) were measured using hand held refractometer and results were expressed in °Brix (AOAC, 2007). Physiological weight loss (PWL) was measured in accordance with procedure described by Kumar et al. (2018). Total soluble sugar (%) was estimated by phenol sulphuric acid method (Thimmaiah, 1999). Titratable acidity of fruit pulp juice was determined by titration with aid of a pH meter using 0.01 N Sodium Hydroxide (NaOH) and 0.1 % phenolphthalein indicator and expressed in percentage of citric acid (Ranganna, 1986). A part of pulp was dried to a constant weight in a hot air oven at 70 °C for calculation of its water content. Total phenolic in pulp and peel was estimated using Folin– Ciocalteu spectrophotometric method (Singleton and Rossi, 1965) described detailed by Hanifa et al. (2016). The results were expressed in gallic acid equivalents (GAE; mg 100 g⁻¹ F.w.). Total flavonoid compounds were estimated according to Bharathi et al. (2014).

The DPPH (2, 20-diphenyl-1-picrylhydrazyl) assay was led Brand-Williams et al. (1995) method with certain modifications as suggested by Rop et al. (2016). For this, a stock solution of DPPH (24 mg) with 100 mL methanol was prepared and stored at −20 °C. The working solution was derived by mixing 10 mL stalk solution with 45 mL methanol of absorbance 1.1 ± 0.02 units at 515 nm. The working solution was permitted to react with 2850 mL of the DPPH solution for 1 h in the spectral wavelength. Afterwards, fruit pulp extracts (150 mL) were permitted to react with 2850 mL of the DPPH solution for 1 h in the dark followed by absorbance were recorded at 515 nm. The results were expressed in ROS scavenging capacity (%). Ferric Reducing Antioxidant Potential (FRAP) was done according to Benzie and Strain (1996) with some modifications. FRAP determined based on concept of at low pH, reduction of ferric tripyridyltriazine (Fe³⁺-TPTZ) complex to the ferrous form, which has an intense blue colour, can be monitored by measuring the change in absorption at 593 nm on spectrophotometer (Rajurkar and Hande, 2011). The results were expressed in ascorbic acid equivalent in mg /100 g of fresh weight.

2.5. Estimating economic viability

Economic feasibility of dragon fruit cultivated in rocky basaltic terrain using different trench soils was computed in term of annual total cost includes both variable and fixed costs, net profit (return) and benefit cost ratio and payback period (Galinato et al., 2014). In estimating variable cost, investments made on establishing orchard, cultivation practices, harvest, packaging and marketing activities, overhead charges and capital interest were calculated. The fixed cost was worked out by summation of depreciation, interest, housing cost, taxes and insurance, management and misc. supplies charges for each year in expected life (25 years) of dragon fruit orchard. Net profit (return) was determined as difference between gross income and total cost in particular year. The benefit cost ratio is ratio of sum of net benefit of returns (B) to the sum of total cost (C). If value of B: C ratio is > 1.00, then the investment in fruit orchard is deliberated as economically viable.

2.6. Statistical analysis

The PROC GLM procedure in SAS software package (ver. 9.3.) was used for data analyses and evaluating pit and trench soil treatments effects on yields and storage quality of dragon fruits. As the experiments followed a completely randomised block design (RCBD), treatments effect in each year and over six years (fruit seasons) was evaluated by individual and combined analysis of variance (ANOVA) as suggested by (Gomez and Gomez, 1984). The treatments means were separated by least significant differences (LSD) at 5 % probability using Duncan’s Multiple Range Test (DMRT) test and Student’s t-test at (p < 0.05). The graphs depicting changes in physico-chemical quality characteristics were expressed in mean values ± SE (p < 0.05) during storage were plotted in Microsoft Excel (2010).

3. Results

3.1. Fruit yield and physical quality traits for marketability

Fruit yields monitored during fruit seasons of 2015 to 2020 from different trench and pit soils are presented in Table 3. Pooled analysis showed marked differences in total fruit yield (TFY), marketable fruit yield (MFY) and yield losses for different trench and pit soil treatments and their interactive effect with seasons. Fruit bearing was initiated during the 2014 itself but was scanty. Hence the marketable yield were recorded from 2015 onwards and considered as 1st fruit season. The maximum MFY (17.1 Mg ha⁻¹) was recorded during 4th year followed by 2nd and 3rd year (15.2–16.0 Mg ha⁻¹) but a decline was observed after 4th year. Benefits in TFY were more with T-mixed soil (44.4 %) as compared with T-black soil (33.1 %) and T-native soil (12.1 %). Similarly, improvement in MFY ranged between 26.0 and 75.0 % (average 51.2 %) for different years with TFY were more with T-mixed soil while the corresponding figures were 32.3–71.1 % (average 38.8 %) with T-black soil and 5.8–38.4 % (average 17.8 %) with T-native soil. Higher decline in MFY (21 %) was observed compared with 2nd to 4th years yields while the decline equalled 5.7 and 12 % in T-mixed and T-native soil, respectively. Surprisingly, this decline was higher (19.4 %) in P-control next to the T-black soil. Comparison of yield losses for normal rain (2nd to 4th year) with above normal rainfall (5th and 6th) years further show that losses increased by 1.75 fold in black soil but remained almost similar in T-native, T-mixed soil or P-control.

The marketable quality of dragon fruit expressed in term of fruit weight, fruit size metrics (geometric mean diameters, Dgm and shape index, SI), moisture content and pulp/peel ratio varied between seasons and as also for different soils (Table 4). Larger sized fruits vis-a-vis weight, optimal pulp moisture content and pulp/peel ratio of fruits produced on mixed, T-native, T-mixed and T-black soil was 40, 28.7 and 9.5 g more than T-native soil while the corresponding figures were 32.3–71.1 % (average 38.8 %) with T-black soil and 5.8–38.4 % (average 17.8 %) with T-native soil. Higher decline in MFY (21 %) was observed compared with 2nd to 4th years yields while the decline equalled 5.7 and 12 % in T-mixed and T-native soil, respectively. Surprisingly, this decline was higher (19.4 %) in P-control next to the T-black soil. Comparison of yield losses for normal rain (2nd to 4th year) with above normal rainfall (5th and 6th) years further show that losses increased by 1.75 fold in black soil but remained almost similar in T-native, T-mixed soil or P-control.

3.2. Biochemical and antioxidant potentials

Biochemical and antioxidant potentials of freshly harvested fruits produced are plotted in Fig. 3A-E. Total soluble solids (TSS) averaged 12.6, 12.1, 11.7 and 11.0–B in pulp of fruits from P-control, T-native, T-mixed and T-black soils, respectively while it varied between 10.9 and 12.8–B for different fruit seasons. Whereas, TSS in fruit peel varies between 3.5 and 3.9–B for differ-
ent fruit seasons with highest 3.9 \text{ C} in both native soil trench and pit treatments (Fig. 3A). Similar trends were observed in total sugar contents of pulp as well as peel (Fig. 3B). With contents of 0.53 and 0.83 mg GAE g$^{-1}$ of fruit pulp and peel, phenol values were highest in P-control followed by 0.52 (pulp) and 0.82 mg GAE g$^{-1}$ (peel) in T-native soil but not significantly different (Fig. 3C). Similarly total flavonoid compounds (TFC) in fruit pulp increased in peat and pollen ranged between 0.58 and 0.65 in P-control followed by 0.57–0.64, 0.52–0.60 and 0.48–0.56 mg RE g$^{-1}$ in fruits from T-native, T-mixed and T-black soils, respectively (Fig. 3D). Similar to TPC and TFC, FRAP was highest in fruits from native soils (T-native and P-control) followed by T-mixed and T-black soils (Fig. 3E).

3.3. Fruit quality during storage

Physiological weight loss (PWL) of fruits increased with storage period and rate of PWL was the minimum in fruit grown on native soil in both trench and pit. Respective PWL after 4 week's storage was 7.1, 7.7, 8.7 and 10.0 % in fruits from T-native, P-control, T-mixed and T-black soils (Fig. 4A). Total soluble solids (TSS) in fruit pulp increased initially and peaked (13.2–14.3 \text{ B}) at 8th day and thereafter the values declined to 9.6–11.1 \text{ B} at the end of 4-week's storage (Fig. 4B). Amongst the treatments, highest TSS was recorded in fruits harvested from native soil (11.1–14.0 \text{ B}) in P-Control and followed by T-native (10.6–14.3 \text{ B}), T-mixed (10.1–13.6 \text{ B}) and T-black (9.6–13.2 \text{ B}) soils. Similar trend was also observed in total sugars though these peaked at 16–20 days of storage and were maximum in native soil (P-control and T-trench) and followed by T-mixed and T-black soils (Fig. 4C). Titratable acidity (TA) declined during storage but higher values were maintained in fruits from P-control and T-mixed soil followed by T-native and T-black soil (Fig. 4D).

Both TPC and TFC contents showed slight reduction initially, but after 8th days onwards TPC values increased and were maximum on 16th day (Fig. 4E-F). The evolution of TPC and TFC was higher in pulp of fruits from native soil (P-control and T-trench). TPC content ranged from 49.6 to 67.1, 48–70.3, 47.2–64.1 and 44.9–56.9 mg GAE100 g$^{-1}$ in fruit pulp from P-control, T-native, T-mixed and T-black soils, respectively while the corresponding TFC varied between 58.6 and 69.5, 56.0–68.1, 52.1–63.0 and 49.5–59.4 mg RE 100 g$^{-1}$. Fruit pulps from the all treatments showed variable and higher AOA in both DPPH and FRAP’s assays. The characteristic AOA trend of increase until 16th day and decrease thereafter is principally attributed to variations in multiple phenolic flavonoids compounds occurred in storage. DPPH activity exhibited in term of ROS scavenging capacity was observed highest (46.1–71.6 \%) in fruits harvested from the native soil for both pit and trench treatment than other soils (Fig. 4G). Besides FRAP antioxidant activity for fruits pulp was ranged between 3.2 and 4.8, 3.1–4.9, 2.9–4.5 and 2.9–4.3 mg ascorbic acid/g FW in P-control, T-native, T-mixed and T-black soils, respectively (Fig. 4H). It can be inferred that storage quality of fruits significantly affected by different pit and trench soils. But, almost negligible variations in storage quality were observed between fruits harvested from T-native soil and P-control.

3.4. Cost and returns

Economic gains from fruits produced under different treatments seemed very encouraging (Supplementary Table 1). Therefore, their economic viability was compared considering various costs and profits (US $). Total establishment cost was the highest in treatment T-black ($ 45064.8 \text{ ha}^{-1}$) followed by in T-mixed ($ 39337.4 \text{ ha}^{-1}$), T-native ($ 33610.0 \text{ ha}^{-1}$) and P-control ($ 25147.9 \text{ ha}^{-1}$). These equalled 84.5, 83.8, 82.7 and 80.3 \% of total cost in respective treatments. The contribution of expenditure on land preparation ($ 6527.9), spent wash ($ 204.0), spent mushroom

Table 3

| Soil treatments | Fruiting seasons of dragon fruit after transplanting in December 2013 | 1st | 2nd | 3rd | 4th | 5th | 6th | Mean |
|----------------|---------------------------------------------------------------|-----|-----|-----|-----|-----|-----|------|
|                |                                                              | 2015| 2016| 2017| 2018| 2019| 2020|      |
| T-Native (N)   |                                                              | 5.6 | 16.3 | 15.1 | 18.9 | 14.6 | 13.2c | 13.9 \* |
| T-Mixed (B:N)  |                                                              | 7.5 | 20.1 | 21.4 | 19.5 | 20.5 | 18.4a | 17.9 \* |
| T-Black (B)    |                                                              | 8.4 | 18.7 | 18.2b | 21.3 | 17.5b | 15.3b | 16.5b |
| P-(Control)    |                                                              | 5.1 | 14.9 | 13.1c | 17.1c | 12.8c | 10.7c | 12.4c |
| Mean           |                                                              | 6.8 | 17.5 | 16.9 | 19.2 | 16.3 | 14.4 | 15.2 |
| LSD (p = 0.05) |                                                              | 0.88 | 1.77 | 1.53 | 1.60 | 1.34 | 2.08 | 1.12 |

| Marketable fruit yield (MFY), Mg ha$^{-1}$ | Year | Soil | Year × Soil |
|------------------------------------------|------|------|-------------|
| T-Native (N)                             | 5.0c | 14.7b | 13.8c        |
| T-Mixed (B:N)                            | 6.7c | 18.7c | 19.3c        |
| T-Black (B)                              | 8.1c | 17.6c | 16.1c        |
| P-(Control)                              | 4.7c | 13.0c | 11.8c        |
| Mean                                     | 6.2c | 16.0c | 15.2bc       |
| LSD (p = 0.05)                           | 0.87 | 1.26 | 1.49         |

| Fruit yield losses, Per cent (%) | Year | Soil | Year × Soil |
|----------------------------------|------|------|-------------|
| Native                           | 10.5b | 9.7b | 8.4c       |
| Mixed (B:N)                      | 9.1c | 7.0c | 9.2bc      |
| Black                             | 3.9d | 5.8c | 11.2d      |
| P-(Control)                      | 14.5d | 12.8d | 9.9c       |
| Mean                             | 9.5e | 8.8d | 9.7c       |
| LSD (p = 0.05)                   | 1.08 | 1.29 | 0.87       |

At the p = 0.05 level, * indicate the significant and ** non-significant differences in mean values of Soil, Year and their interactions. DMRT test (p = 0.05) results indicate that values in a column followed by similar letters for soil treatments are not significantly different. While the DMRT values in a row followed by similar letter for mean are not significantly different.
Changes in physical quality traits of dragon fruits as affected by trench and pit soil during fruiting seasons of 2015–2020.

and these were $11664.1, $6518.2, $1372.2 and $1294.7 for hectare. Whereas expenditure on trench/pit soils treatments varied planting material ($1035.8) and drip system ($480) was remained substrate ($840.5), trenching ($11102.2), trellis system ($5504.4), fertiliser, chemicals, electricity and manpower; harvest, packaging and market activities; interest and overhead charges) per hectare were reported to between $3712.9–5045.2, $3616.9–5010.7, $3447.5–4768.6 and $3412.1–4597.0 per hectare for T-black, T-mixed, T-native and P-control soils, respectively. Moreover, the operational cost keeps on increasing up to 4th years (2018) of production and afterward it becomes almost stabilised. Corresponding values of annual fixed costs were remained constant i.e. $1544.4, $1537.5, $1530.6 and $1520.5 per hectare. The total cost per hectare varied from $5257.3–6589.6, $7510.2–6548.2, $4978.2–6299.0, $5442.2–6117.5 for T-black, T-mixed T-native and P-control soils during production years. Annual gross return from fruit production per hectare worked out to be ranged between $8816.3–21659.9, $7510.2–21006.8, $5420.4–17741.5 and $5113.6–15558.3 for T-black, T-mixed, T-native and P-control soils, respectively.

4. Discussion

4.1. Fruit yield and marketability

Apart from the healthier growth in establishment phase of dragon fruit, comparatively cooler climate (mean monthly air temperatures being 0.15–1.10 °C less) and lower relative humidity (less by

| Soils            | Physical quality traits of dragon fruits during different seasons |
|------------------|------------------------------------------------------------------|
|                  | 1st                    | 2nd                    | 3rd                    | 4th                    | 5th                    | 6th                    | Pooled                |
|                  | 2015                  | 2016                  | 2017                  | 2018                  | 2019                  | 2020                  |                     |
| Fruit weight (g) | T-Native (N)           | 281.2b                | 293.2b                | 277.7b                | 278.5b                | 269.2b                | 233.5b                | 272.2c                |
|                  | T-Mixed (B:N)         | 309.1a                | 320.2a                | 312.8a                | 315.5a                | 285.4a                | 274.4a                | 302.9b                |
|                  | T-Black (B)           | 315.4a                | 311.8a                | 297.1b                | 300.1b                | 272.2b                | 251.8b                | 291.4a                |
|                  | P-Control             | 275.0b                | 289.5b                | 266.5b                | 267.6b                | 248.6b                | 228.9b                | 262.7b                |
|                  | Mean                  | 295.2b                | 303.7b                | 288.3b                | 290.5b                | 268.9b                | 247.2b                | 282.3                 |
| LSD (p = 0.05)   |                      | 6.61                  | 12.92                 | 10.09                 | 11.23                 | 11.92                 | 10.89                 | 6.45                  |
| Geometric mean diameter (Dgm), cm | T-Native (N) | 10.1b                 | 11.0b                 | 10.3b                 | 10.6b                 | 9.1b                  | 8.3b                  | 9.9b                  |
|                  | T-Mixed (B:N)         | 10.8b                 | 12.2b                 | 11.1b                 | 11.4b                 | 9.9b                  | 9.6b                  | 10.8b                 |
|                  | T-Black (B)           | 10.1b                 | 11.5b                 | 11.4b                 | 11.7b                 | 8.9b                  | 8.6b                  | 10.4b                 |
|                  | P-Control             | 10.0b                 | 10.4b                 | 9.5b                  | 9.5c                  | 8.6b                  | 8.0d                  | 9.3b                  |
|                  | Mean                  | 10.2b                 | 11.3b                 | 10.6bc                | 10.8b                 | 9.2c                  | 8.6b                  | 10.1b                 |
| LSD (p = 0.05)   |                      | 0.35                  | 1.31                  | 0.76                  | 0.66                  | 0.48                  | 0.25                  | 0.43                  |
| Shape Index (SI) | T-Native (N)           | 0.981ab               | 0.961b                | 0.962a                | 0.965b                | 0.940b                | 0.939b                | 0.958b                |
|                  | T-Mixed (B:N)         | 0.966b                | 0.947b                | 0.955b                | 0.954b                | 0.937b                | 0.932*                 | 0.933b                |
|                  | T-Black (B)           | 0.965b                | 0.938b                | 0.934b                | 0.932b                | 0.912b                | 0.904b                | 0.931b                |
|                  | P-Control             | 0.998a                | 0.979b                | 0.989b                | 0.994b                | 0.968b                | 0.946b                | 0.979b                |
|                  | Mean                  | 0.978a                | 0.956bc               | 0.961b                | 0.964b                | 0.939bc               | 0.930b                | 0.955                 |
| LSD (p = 0.05)   |                      | 0.023                 | 0.027                 | 0.037                 | 0.025                 | 0.036                 | 0.040                 | 0.025                 |
| Moisture content (%), pulp | T-Native (N) | 0.730b                | 0.745bc               | 0.723b                | 0.711b                | 0.709bc               | 0.684bc               | 0.716b                |
|                  | T-Mixed (B:N)         | 0.756a                | 0.771a                | 0.765a                | 0.751b                | 0.754b                | 0.741b                | 0.756b                |
|                  | T-Black (B)           | 0.771a                | 0.760ab               | 0.750a                | 0.754b                | 0.731ab               | 0.704b                | 0.745b                |
|                  | P-Control             | 0.722a                | 0.731a                | 0.709b                | 0.691b                | 0.688b                | 0.659b                | 0.700b                |
|                  | Mean                  | 0.745bc               | 0.752a                | 0.732bc               | 0.732bc               | 0.719b                | 0.695b                | 0.745b                |
| LSD (p = 0.05)   |                      | 0.015                 | 0.020                 | 0.024                 | 0.018                 | 0.012                 | 0.025                 | 0.017                 |
| Combined analysis over years | T-Native (N) | 80.40                 | 81.9b                 | 82.9bc                | 82.6c                 | 83.1bc                | 84.8c                 | 82.6c                 |
|                  | T-Mixed (B:N)         | 82.2m                 | 82.6m                 | 83.4c                 | 83.7m                 | 84.8c                 | 85.6m                 | 83.7m                 |
|                  | T-Black (B)           | 83.5m                 | 83.9m                 | 85.7m                 | 85.2m                 | 86.1m                 | 87.6m                 | 85.4m                 |
|                  | P-Control             | 80.1d                 | 80.9m                 | 81.4c                 | 81.3m                 | 81.2c                 | 83.1c                 | 81.3c                 |
|                  | Mean                  | 81.6d                 | 82.3c                 | 83.4bc                | 83.2bc                | 83.8bc                | 85.3c                 | 83.3                  |
| LSD (p = 0.05)   |                      | 2.51                  | 1.61                  | 1.57                  | 0.99                  | 1.76                  | 1.40                  | 1.21                  |

At the p = 0.05 level, * indicate the significant and ** non-significant differences in mean values of Soil, Year and their interactions. DMRT test (p = 0.05) results indicate that values in a column followed by similar letters for soil treatments are not significantly different. While the DMRT values in a row followed by similar letter for mean are not significantly different.
Fig. 3. Interactive effect of trench and pit soils and fruiting seasons on biochemical and antioxidant potentials of dragon fruits during 2015–2020.
2.2–6.8 %) mostly coincided with bud initiation, flowering and fruit development stages during initial years. This seems to have promoted productivity. With advancement in years leads to yield stabilization in dragon fruit after 4th year of planting. Earlier Nerd et al. (2002) and Goenaga et al. (2020) have reported beneficial impacts of congenial weather conditions on growth and fruit yields. Conversely, above normal rainfall, 739 and 936 mm was received during 2019 and 2020. Specifically more rain showers occurred during bud formation and flowering stages. This usually results in bud/flower drop and fruit rotting thereby reduced fruit
yields (Ortiz-Hernández and Carrillo-Salazar, 2012; Karunakanar and Arivalagan, 2019).

Significant improvements in fruit yield were monitored when conventional practice of pit formation with native soil (i.e. P-Control) was replaced with trench soils. Obviously this was the consequence of maintenance of better moisture regimes, nutrition conditions and other soil properties like soil structure to improve aeration in the rooting zone of the plants (Table 2). For example increased K availability is known to stimulate the photo-assimilates transportation to storage organs (fruits) in plant and contributing towards sugar formation and translocation (Fernandes et al., 2018). It also affects plant growth by maintaining cell turgidity, enlarged fruit size, increases acidity and fruit yields in other horticultural crops (Fallahi et al., 2010; Stino et al., 2011, Wu et al., 2020). Conversely, plants have to face various edaphic stresses due to lower water-holding capacity, nutrient retention, P-fixation and low organic carbon in these shallow native soils which restrict the plant growth vis-a-vis fruiting (Marathe et al., 2015; Prodhah et al., 2018). The prolonged wetness of black soil owing to higher clay content results in aerations problems especially during rainy season (Bandyopadhyay et al., 2007). Anoxic conditions further impact nutrient supplies and the plant growth ultimately gets affected on these clayey soils (Bandyopadhyay et al., 2007; Wu et al., 2020). Such effects were visualised in black soil during 5th and 6th year when rainfall was above normal. This may be due to lack of percolation and seepage of rain water from the pit surrounded by the comparatively impermeable rock strata even if pit filled with murrum soils a key factor responsible for anoxic conditions. Non-uniform maturity, disease infection, water loss and rotting behaviours of the fruits accountable for reductions in MFY are expressed in term of percentage of fruit yield losses (Nguyen et al., 2020). Average yield losses across 6 years were 12.5, 10.3, 8.7 and 9.1 % under P-control, T-native, T-mixed and T-black soil treatments, respectively, indicating stress induced deformities to be the maximum under pit followed by trench filled with native soil. Deformities like abscission and maximal ventral peel cracking as induced with anoxic conditions were observed to be higher more during fruit ripening stage in T-black soil. Zhu et al., (2016) also observed similar serious dragon fruit cracking in orchard with high-clay soil than the other soils. Nevertheless, incidental attack of ants, scale insect and birds, fruit water loss in dry and hot environment and rotting by fruit flies under excess rainfall may also have contributed towards higher yield losses (Perween et al., 2018).

The quality of dragon fruit varied significantly under different planting conditions with varying soil mixtures. In general, trench planting with mixed soils resulted a positive impact on product quality, nonetheless some deviations in impact were also observed on the quality. Analogous dissimilarities in other fruits crops cultivated under varied soil conditions have been reported earlier also (Aruani et al., 2014; Wakchaure et al., 2020). Weather conditions during fruit development and age of plants also affected marketable quality attributes. In the present study, pulp/peel ratio was reduced after 2nd cropping season. Changes in pulp to peel ratio is known to be related to fruit moisture content, cell osmosis, osmotic potential and fruit size matrices, which are controlled by root water uptake and transpiration by plants under different soils and weather conditions (Newilah et al., 2011; Kim et al., 2020).

4.2. Biochemical and antioxidant potentials

Higher TSS was observed under P-control. Abiotic stresses as induced by mineral deficiency, soil composition and environmental conditions usually alter TSS and sugars of fruits (sink) in fruit crops (Lemoine et al., 2013) as also the deficiencies of major nutrients like N and results in accumulation of sugar and carbohydrates (Kim et al., 2020). Total phenolic content (TPC) in peels was almost one and a half times of that in fruit pulp. The overall higher biochemical quality attributes in fruits from P-control and T-native soils indicate that though water transport by roots from native murrum soil may be reduced but not the source sink photo-assimilates (Zegbe et al., 2006). Since TPC contributes to strengthen non-enzymatic defence system thereby helping to alleviate the adverse impacts of oxidative stress, this resulted in higher TPC accumulation in fruits of native soil (Hasanuzzaman et al., 2020; Hossain et al., 2021). However, the reduced values of TPC and TFC in fruits from T-black soils contradict the earlier results by Zargoosh et al. (2019) who reported their considerable improvement in fertile soils. Among the different methods designed for monitoring antioxidants activity (AOA), ascorbic acid was analysed using FRAP assays since its high ability to scavenge active oxygen species and free radicals by stimulating oxidative reactions. It seems that smaller fruit size and low dilution resulting from increased soil water depletion in native soil lead to accumulation of assimilates thus enhanced the biochemical and antioxidant potential (Yuqing et al., 2015; Garrido et al., 2016). Fruit yields, size and weight have also been reported to be inversely related to AOA (Wang et al., 2019; Huang et al., 2019).

4.3. Fruit quality during storage

Since the prices of fruits are determined based on their quality when brought to the market for selling, periodic changes in their quality parameters during storage were monitored and are included in Fig. 4A-G. Initial moisture content and fruit size seem to control PWL. Higher water content and its losses during storage caused fruit softening, peel translucency and scale darkening in fruits harvested from T-black soil. These symptoms were not observed in fruits from T-mixed, T-native and P-control soils. Optimal water levels in fruits have been reported to reduce cell metabolism and delay senescence during storage (Jadhav, 2018).

Irrespective of treatments, TSS increased progressively with the storage period and then reduced. The initial rise in TSS is usually ascribed to hydrolytic breakdown of carbohydrates to simple sugars and solubilisation of pectin in stored fruits (Mishra and Kar, 2014; Chaemsanit et al., 2018) while later decline occurs due to metabolic diversion of sugar and starch products involved in biosynthesis pathways to meet the needs of carbon in repairing damaged cell to protect fruit decay (Wakchaure et al., 2020). Concurrent to TSS, sugar content also increased with the storage period and then decreased. Wang et al. (2019) reported that soil moisture content is highly and negatively correlated with organic acids, and carbohydrates. Since fruits harvested from native soil were having lower moisture content and higher organic acids, carbohydrates, which could be converted into sugar resulting higher TSS. Later, decline in total sugars was associated with their consumption in respiration processes during storage (Kolniak-Ostek et al., 2014). Similar findings were also reported in tomato and strawberry fruits (Agbemafle et al., 2014; Bishnoi et al., 2015). Utilisation of organic acid and degradation of ascorbic acid in metabolic process during storage are ascribed to be reason for slow declines of TA (Chaemsanit et al., 2018; Panchal et al., 2018).

Greater variation in phenol and flavonoids was observed. These variations in fruit TPC and TFC are obviously associated with evolving mechanism of plant tolerance to stress conditions (Choo et al., 2011; Batista et al., 2016). Total phenolic and antioxidant flavonoid contents are related to water stress, high temperature and evapotranspiration. Thus relatively higher TPC and TFC contents in fruits stored from native soil can be attributed to water stress incurred during its growth. Similar increases in total phenolic, flavonoids and anthocyanins in controlled atmospheric storage have been
previously reported in other fruits (Ayala-Zavala, 2004; Hoang et al., 2011; Chaemsanit et al., 2018).

Conversely, AOA assessed by DPPH increased with storage period suggesting facts that estimated antioxidant potentials of the dragon fruits may be more related with vitamin C rather than other antioxidant compounds. Thus occurrence of alternate mid-drought stress conditions and full irrigation/rainfall in native soils during fruit seasons helped in synthesis of more secondary metabolites which triggered the AOA activity. This is well augmented the fact that Vitamin C, phenolics and flavonoids describes the main water-soluble antioxidant potential in fruits and contributing to the AOA (Kumar et al., 2015). AOA of stored fruits has been reported to vary substantially with the genetic variety, cultivation practices, ripening stages, soil and other growing conditions (Mustafa et al., 2018; Zargoosh et al., 2019).

4.4. Economic implications

Annual net return and B: C ratio per hectare at different ages (2013–2020) of dragon fruit orchard are illustrated in Fig. 5. Net return and B: C ratio remained negative in establishment year (2013–14) since the fruit bearing was just initiated and improved during the following years. Whereas their corresponding values become positive and increased for initial two production years (2015 and 2016) and then remained almost static or declined slightly in consequent years. These results are largely associated the full production of dragon fruits which usually starts after attaining the age of three years. When averaged for gross and net returns of production years (2015–2020), corresponding B: C ratio was found to be maximum (1.85) in T-mixed, intermediate in T-black (1.68) and lowest (1.32) in T-native and P-control (1.10) soils, respectively. Since B: C ratio was greater than unity, indicating the investment made on dragon fruit orchard was economically viable. The total of net return obtained in initial 4, 5 and 6 years of production was $ 43836.9, $ 39252.7 and $ 52971.1 per hectare in T-mixed, T-native, T-black, respectively. Those were higher than corresponding values $ 40889.6, $35155.4 and $ 46623.9 of establishment cost incurred per hectare. While in case of P-Control higher net return ($ 32993.6) has been obtained in 5th years than establishment cost ($ 26553.6 ha$^{-1}$). Thus, the payback period of investment of dragon fruit orchard was four, five, six years for T-mixed, T-native and P-Control, T-black soils, respectively. The payback period of T-mixed soil was 42.8 % lower than guava (7 years) orchard, the most prevalent fruit in the area (Kumar et al., 2019). Thus growing dragon fruit in trench mixed soil could be more economic viable options and hence could be preferred as profitable enterprise. Moreover, dragon fruit cultivation is a one of potential step towards the diversification and commercialization of agriculture in degraded land regions of India.

5. Conclusions

Water scarcity, low soil fertility and poor root anchorage are the key constraints limiting sustenance of orchards in shallow basaltic degraded regions. Opting for viable soil and water management practices which enhance water and nutrient supplies and high value fruit cultivation can promote livelihoods of resource poor farmers. In the present study, leaving the initial two years of orchard establishment, dragon fruit proved to be highly remunerative crop with average annual MFY of 14.3 ± 0.6 Mg ha$^{-1}$ even on native soils using trench practice. Mixing of black soil with native soil in equal proportions while filling planting trenches produced highest marketable yield (18.2 ± 0.4 Mg ha$^{-1}$) and mean B: C ratio (1.85) as well as the quality of fruits at harvest and also during storage. This proved more profitable than total replacement of planting trench soil with black soil where fruit productivity and mean of B: C ratio was 16.4 ± 1.1 Mg ha$^{-1}$ and 1.67, respectively. While filling native soil in pit produces lowest fruit yield (12.02 ± 0.8) which was not economical after 6th years where annual B: C is < 1. Hence, a shift...
towards such a module of transforming trench soil with mixture of native and black soil should be useful to protect resource poor grower's interests and socio-economic development of without penalising ecosystem of drought prone regions.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

The authors gratefully acknowledge the support provided by Orchard development and maintenance team ICAR-NIASSM. Further the research work presented was financially supported by the Indian Council of Agricultural Research, National Institute of Abiotic Stress Management, Baramati, Pune, Maharashtra (India).

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sbsct.2022.103497.

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