Path Analysis of Total Economic Product of Twenty-Two Tenera Oil Palms in Krabi, Thailand

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ABSTRACT

The indirect factor that holds significant appeal for farmers and the oil palm industry in assessing the potential of Tenera oil palm plantations is the total economic product (TEP). This comprehensive study, conducted at the Hong Sila Agriculture and Industry Company Limited in Krabi, Thailand, evaluated the factors influencing the TEP from twenty-two Tenera oil palms. The factors considered in TEP were fresh fruit bunch (FFB) recorded for 11 years from 2011 to 2021 and bunch components evaluated for four years from 2017 to 2020 using a randomized complete block design with four replicates. The results revealed that the factors influencing TEP were oil yield (OY) and kernel yield (KY), with OY having a more direct impact than KY. The kernel to bunch (KTB) and oil to bunch (OTB) multiplied by FFB are equal to KY and OY, so these two factors were factor affections. The factors that directly influenced OY were FFB and OTB, with no significant correlation between FFB and OTB and a small indirect effect of FFB through OTB. The strong direct effect of character on KY was obtained from KTB, followed by FFB, with a higher total effect of KTB over FFB. The average TEP in 22 Tenera oil palms was 64.41 kg/palm/year, with T22 giving the highest TEP at 74.55 kg/palm/year, while T12 displayed the lowest TEP at 53.86 kg/palm/year. TEP is the one parameter known for Tenera's potential to get more profit from the factors of FFB, OTB, and KTB, which was the one purpose for plant breeding to calculate for the selection process.

Keywords: correlation coefficient; regression; oil yield; kernel yield; fresh fruit bunch

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INTRODUCTION

In 2023/2024, the United States Department of Agriculture (2023) reported that palm oil emerged as the leading source of vegetable oil, capturing an impressive 45.4% market share. This dominance is attributed to the significant production of 79.5 million metric tons (MMt) of crude palm oil (CPO) and 9.03 MMt of palm kernel oil (PKO). Other vegetable oils, such as soybean, rapeseed, and sunflower seeds, are followed by lower volumes of 61.9, 33.1, 22.1, and 17.9 MMt, respectively.

Palm oil is extracted from two parts of the palm fruit: the mesocarp and kernel. CPO is a type of vegetable oil derived from the fruit of the palm tree in the mesocarp or reddish pulp, whereas PKO is extracted from the kernel. According to Basiron (2001), fresh fruit bunches (FFB) of the Tenera variety typically yield an average of 4 tons of palm oil, 0.5 tons of PKO, and 0.6 tons of palm kernel cake (PKC) per hectare per year. CPO and PKO serve as raw materials for a variety of food products, including cooking oil, margarine, ice cream, and dietary supplements, as well as non-food items, such as soap, explosives, and humectants. In addition, CPO and PKO are utilized in the oleochemical industry to produce fatty acids, esters, alcohols, and glycerol, which are essential for soaps, detergents, cosmetics, personal care products, lubricants, greases, printing ink, and biodiesel (Othman et al., 2022).

To enhance production efficiency, it is crucial to increase the yield of oil palm bunches per plantation, as measured by the annual production of FFB per palm per year. By 2024, Indonesia is expected to host the largest global oil palm plantations, covering 14.95 million hectares. Thailand ranks fourth in the world, with 0.98 million hectares distributed across its Southern, Central, Northeast, and Northern regions, accounting for approximately 0.89 million hectares, 0.09 million hectares, 0.04 million hectares, and 0.01 million hectares, respectively (Office of Agricultural Economics, 2024). Thailand has set a target as part of the "Plan to Reform the Oil Palm and Palm Oil Sector (2017-2036)," aiming for a fresh fruit bunch (FFB) yield of approximately 21.9 tons per year per plantation by 2036. This represents an increase from the 18.3 tons per year recorded in 2023 (Office of Agricultural Economics, 2017). Breeding programs for oil palm face complexities to improve phenotypic and agronomic traits. The primary goal of these programs is to enhance oil production through direct morphological changes and genetic evaluations. Path analysis is a unique requirement for specifying the relationships between independent variables. This specification results in a model that elucidates the causal mechanisms through which independent variables exert both direct and indirect effects on dependent variables. (Wright, 1923). Path coefficient analysis showed significant correlations between direct and indirect effects, demonstrating the importance of gene utility for oil palm progenies in breeding efforts (Sara et al., 2018).

The main factor for palm yield is the FFB, which is correlated to the bunch number (BNO) and average bunch weight (ABW) (Tanya et al., 2013). The first step from oil palm plantation to industry is to directly sell or pass the palm bunch to the oil palm bunch collection center by weighing the palm bunch on a scale. Then, the separation process from bunch to fruit and fruit to mesocarp and kernel is the next step to obtain the value from oil to bunch and kernel to determine the oil yield and kernel yield, as well as the correlation with the previous report. Okoye et al. (2009) reported that the highly significant correlation between OY and FFB was 0.724, OY and BNO were 0.569, and OY and oil to bunch (OTB) was 0.589, supporting Nor Azwani et al. (2020) noted that strong and positive correlations of FFB and OTB with OY suggested that OY can be improved by increasing FFB yield or OTB. Suzana et al. (2020) reported that the positive correlation between KY was FFB (0.911) and KTB (0.782), and negatively correlated with OTB (-0.394). Therefore, advocating this action plan for high yield per area involves breeding and developing essential traits that enhance yield efficiency within limited areas.

This study is particularly significant as it seeks to identify the potential of these traits by estimating the factors correlated with the impact of economic characteristics on total economic production (TEP) for an oil palm breeding program.

MATERIALS AND METHOD

Tenera oil palm materials

Twenty-two Tenera oil palms from Goldentenera Company Limited, Univanich Oil Palm Company Limited, and the Department of Agriculture were planted in November 2009 at Hong Sila Agriculture and Industry Company Limited in Krabi Province. The coordinates are latitude 8°17'41.5"N and longitude 99°05'03.7"E. The plantation is sandy and loam-textured, as determined by the hydrometer method with a pH value of 6.49, measured using a 1:1 soil-to-water ratio (University of Illinois at Urbana-Champaign, 2004), and contained 1.42% organic matter, as determined by the Walkley and Black titration method (Walkley and Black, 1934), and an average annual rainfall of 2,240 mm (2012-2021) (Thai Meteorological Department, 2021). The experiment employed a randomized complete block design, with four replicates. Each replication consisted of 15 palm trees arranged in a triangular configuration at a distance of 9×9×9 m.

Phenotype recording and data analysis

The data on oil palm yield, representing the annual production of FFB/palm in kilograms, were gathered from oil palm plantations from January 2011 to December 2021, 3 to 13 years after planting, whereas data on oil yield and kernel yield were calculated using TEP (Kushairi et al., 2001; Mandal and Babu, 2018) from 2017 to 2020, including the process of bunch components starting from bunch weight and then calculating KTB and oil to bunch. TEP was determined using the following equation:

$$TEP = OY + 0.6\,(KY) \qquad (1)$$

where: $OY = \frac{OTB \times FFB}{100}$

$KY = \frac{KTB \times FFB}{100}$

where: FFB = fresh fruit bunch (kg/palm/year), OTB = oil to bunch (%), KTB = kernel to bunch (%), OY = oil yield (kg/palm/year) and KY = kernel yield (kg/palm/year).

Data collection

Total economic product (TEP) data were obtained from the bunch component measured from oil to bunch (OTB; %) and kernel to bunch (KTB; %) using the Ooi (1978) method, while the yield trait was fresh fruit bunch (FFB; kg).

Statistical Analysis

The data were analyzed using R 4.3.1 to examine the analysis of variance (ANOVA), mean comparison, and path analysis on TEP with KY, OY, FFB, OTB, and KTB (R Core Team, 2021).

RESULTS AND DISCUSSION

The analysis of variance revealed a significant difference among the Tenera oil palms regarding TEP, OY, KY, FFB, OTB, and KTB. T20 had the highest total estimated production (TEP) at 74.55 kg/palm/year, exceeding the average of 64.41 kg/palm/year. This elevated TEP was primarily attributed to its high oil yield (OY) of 70.63 kg/palm/year, while kernel yield (KY) was recorded at 6.53 kg/palm/year. The main factor influencing both OY and KY was FFB, which measured 235.15 kg/palm/year. The effects of OTB at 29.95% and KTB at 2.77% were less significant. T21, the second highest in TEP, recorded the highest OTB at 31.04%, with a KTB of 3.11% and an FFB of 216.74 kg/palm/year. T21 comprised the factors with high OY (67.40 kg/palm/year) with the highest OTB at 31.04%, while KY and KTB were 6.81 kg/palm/year and 3.11%, respectively, the FFB of T21 was 216.74 kg/palm/year lower than T20. In contrast, T16 had the highest FFB at 241.08 kg/palm/year, a KY of 10.56 kg/palm/year, and a KTB of 4.30%. However, its TEP was lower, measured at 67.23 kg/palm/year (Table 1 and Figure 1). Norziha et al. (2024) reported TEP from the MPOB-Angola germplasm oil palm across 44 Tenera families in Malaysia. They found that the TEP ranged from 20.90 kg to 60.37 kg per palm per year, with an average of 48.62 kg per palm per year. In our study, the TEP range was higher, between 53.86 kg and 74.55 kg per palm per year, with an average of 64.41 kg per palm per year. Notably, 17 Tenera families in our study had the highest TEP reported by Norziha et al. (2024). Additionally, the average FFB and OTB for twenty-two progenies in this study were 213.87 kg per palm per year and 28.45%, respectively. Both figures exceed the standard set by the Standard and Industrial Research Institute of Malaysia (SIRIM), which specifies a minimum of 170 kg per palm per year for FFB and 25% for OTB (Department of Standards Malaysia, 2005). Our results surpassed these standards by 25.80% for FFB and by 13.80% for OTB. This study highlighted the top five progenies, as they demonstrated a significant positive effect of OY at 0.977**, which was considerably higher than that of KY at 0.165**. Therefore, exploring the factors influencing TEP is essential for understanding both the direct and indirect effects, particularly through path analysis

Path analysis provides more detailed information than correlation analysis because it demonstrates the partitioning of direct and indirect effects on interesting traits or indicates the relative importance of the causal factors involved (Wright, 1921; 1923). In this study, TEP was interested in the factors influencing the long-term potential of palm oil plantations for the decision to choose oil palm varieties. Based on path analysis, five characteristics, OY, KY, FFB, OTB, and KTB, affect the TEP. OY (0.977**) had a greater direct effect on TEP than KY (0.165**). The correlation between TEP and OY was high (0.986**), whereas that between KY and OY was low (0.218*). Corley (2018) noticed that KTB was highly correlated with kernel to fruit (KTF) at 0.968**; therefore, KTF had to be considered as one factor for making KY. The direct effect for OY and KY was from FFB, in which FFB had a stronger positive effect on OY than KY (0.741** and 0.266**, respectively), including correlations of approximately 0.653** and 0.455**, respectively. OTB had a positive effect and a correlation with OY of approximately 0.759** and 0.673**, respectively. KTB for KY has a direct impact of 0.904** and a correlation value of 0.959**, as shown in Figure 1.

Previous research on the correlation between FFB and OY and between FFB and OTB, as reported by various authors, has shown a diverse range of correlation values. Okoye et al. (2007) reported 0.724* and 0.589*; Krualee et al. (2013) mentioned 0.85** and 0.46**; Nor Azwani et al. (2020) displayed 0.69** and 0.60**, and Myint et al. (2021) demonstrated 0.80** and 0.36**. Some reports showed a stark contrast in the correlation between FFB and OTB, with values as low as 0.081 (Balakrishna et al., 2018) and -0.174 (Corley, 2018). In comparison, Ataga (1995) found that the only correlation between FFB and OY was 0.782*.

Table 1 Mean of total economic product (TEP) and yield traits of twenty-two Tenera age 3 to 13 years after planting at Krabi province

Tenera code	TEP (kg/palm/year)		OY (kg/palm/year)		KY (kg/palm/year)		FFB (kg/palm/year)		OTB (%)		KTB (%)	
T1	61.59	d-i	56.29	c-f	8.84	ab	212.22	c-e	26.51	b-e	4.23	ab
T2	65.69	b-f	62.21	a-e	5.80	bc	217.62	b-e	28.44	a-d	2.66	c
T3	56.51	g-i	52.82	ef	6.15	bc	190.22	fg	28.01	a-e	3.22	a-c
T4	70.69	a-c	67.88	ab	4.67	c	221.45	a-e	30.66	a	2.10	c
T5	59.89	e-i	56.18	c-f	6.18	bc	204.32	ef	27.55	a-e	2.99	a-c
T6	69.32	a-d	66.20	a-c	5.20	c	227.80	a-d	29.16	a-d	2.29	c
T7	62.05	c-i	58.95	b-f	5.17	c	213.14	b-e	27.68	a-e	2.40	c
T8	67.50	a-e	63.64	a-d	6.45	bc	209.52	d-f	30.35	ab	3.13	a-c
T9	61.18	d-i	58.70	b-f	4.13	c	213.45	b-e	27.53	a-e	1.95	c
T10	55.45	hi	51.37	f	6.80	bc	210.19	d-f	24.44	e	3.21	a-c
T11	69.50	a-d	65.90	a-c	6.00	bc	215.02	b-e	30.69	a	2.77	c
T12	53.86	i	51.45	f	4.02	c	178.47	g	28.87	a-d	2.25	c
T13	64.50	b-g	61.11	a-f	5.64	c	209.75	d-f	29.12	a-d	2.68	c
T14	58.33	f-i	55.03	d-f	5.50	c	211.46	d-f	26.05	c-e	2.61	c
T15	63.48	b-h	60.75	a-f	4.55	c	202.78	ef	30.17	ab	2.22	c
T16	67.23	a-e	60.89	a-f	10.56	a	241.08	a	25.35	de	4.30	a
T17	68.59	a-d	64.77	a-d	6.37	bc	233.74	a-c	27.71	a-e	2.73	c
T18	65.47	b-f	61.56	a-f	6.51	bc	219.81	b-e	27.97	a-e	2.96	bc
T19	66.09	a-f	63.43	a-d	4.42	c	206.21	d-f	30.79	a	2.14	c
T20	74.55	a	70.63	a	6.53	bc	235.15	ab	29.95	a-c	2.77	c
T21	71.48	ab	67.40	ab	6.81	bc	216.74	b-e	31.04	a	3.11	a-c
T22	64.18	b-g	59.90	b-f	7.14	bc	214.98	b-e	27.87	a-e	3.30	a-c
CV (%)	9.54		10.11		30.52		6.15		8.34		28.84	
Mean	64.41		60.78		6.06		213.87		28.45		2.82	
Minimum	53.86		51.37		4.02		178.47		24.44		1.95	
Maximum	74.55		70.63		10.56		241.08		31.04		4.30	
SD	5.43		5.36		1.51		13.88		1.84		0.61	

Note: TEP=total economic product (kg/palm/year), OY=oil yield (kg/palm/year), KY=kernel yield (kg/palm/year), FFB=fresh fruit bunch (kg/palm/year), OTB=oil to bunch (%), and KTB=kernel to bunch (%).

Means with the same letter are not significantly different at $p<0.05$ based on Duncan's multiple range test (DMRT)

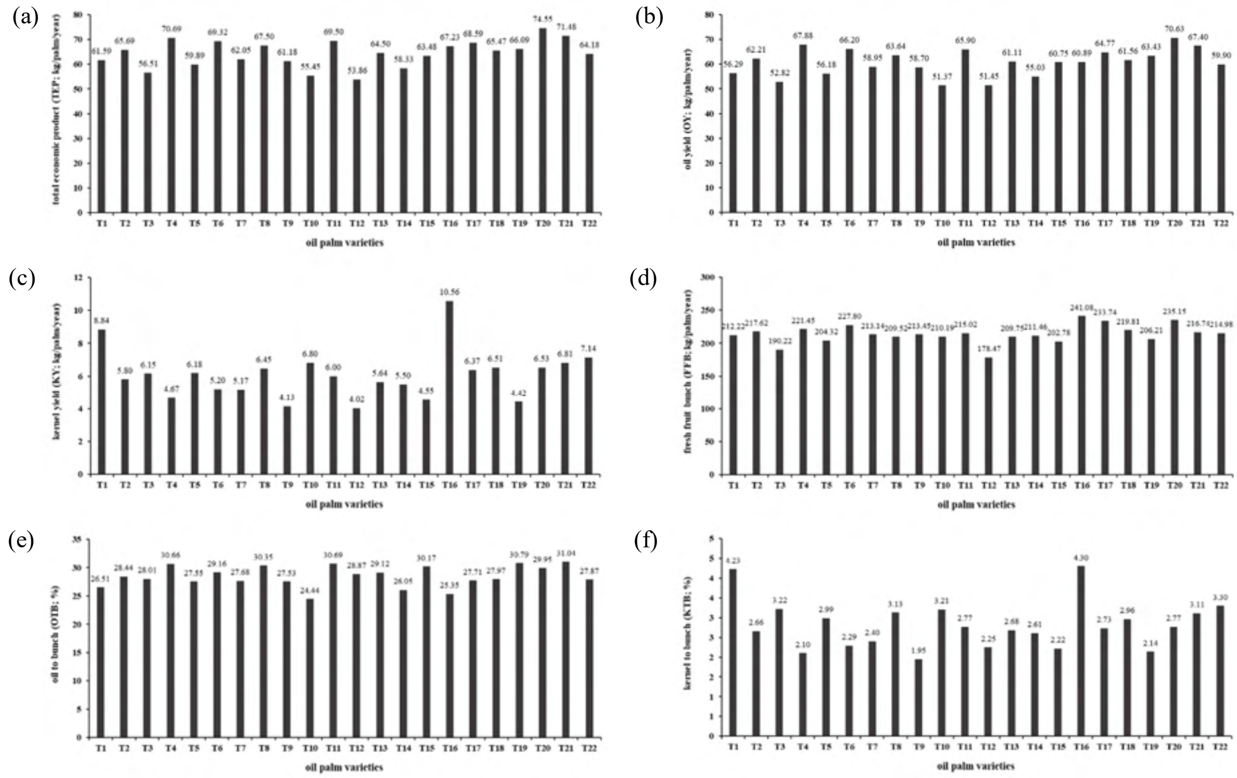

Figure 1 Mean of TEP (a), OY (b), KY (c), FFB (d), OTB (e) and KTB (f) of 22 Tenera oil palms;
Note: TEP = total economic production, OY = oil yield, KY = kernel yield, FFB = fresh fruit bunch, OTB = oil to bunch, KTB = kernel to bunch

However, this result demonstrated a significant direct effect of FFB on OY and KY, which had 0.741** and 0.266** (Figure 2), and the factors that had a direct effect on FFB were BNO and ABW, as reported by Tanya et al. (2013), were 0.94** and 0.98**, respectively. This enlightening information indicates that the amount of FFB depends on the BNO and contrasts with ABW with a negative correlation (-0.49*), meaning that the BNO was high with a small bunch (low ABW) and low BNO with high ABW. In addition, Balakrishna et al. (2018) reported that the influencing factors that directly affected FFB were BNO (0.685**) and ABW (0.861**). Finally, the TEP factor is an alternative factor for oil palm breeders to consider for the selection step in oil palm breeding programs in the future. This will benefit oil and kernel yields, affecting oil production for oil palm planters and the oil palm industry.

CONCLUSION

The improvement to high yield of oil palm by the TEP trait, which will lead to income by breeding programs, can be achieved through OY, and KY has a positive correlation and direct and indirect effects from FFB and OTB from selecting parents with a strong genetic background of the effects of the traits.

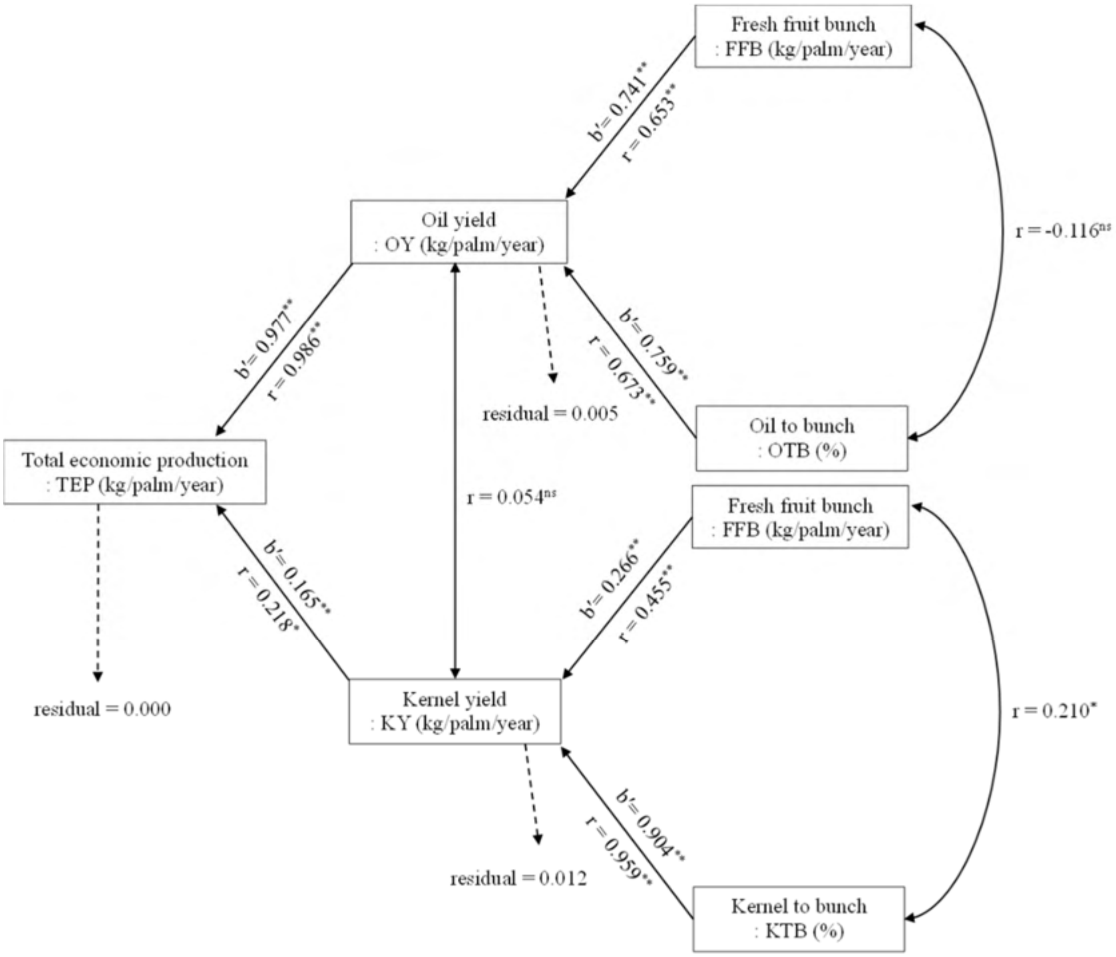

Figure 2 Correlation coefficient and path analysis of total economic product of twenty-two Tenera oil palms in Krabi province

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