

ON HERMITE-BASED MULTI-POLY-GENOCCHI POLYNOMIALS WITH PARAMETERS $a, b,$ AND c

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ABSTRACT. In this paper, we introduced the Hermite-based multi-poly-Genocchi polynomials with parameters $a, b,$ and c by means of multiple polylogarithm. We then derive some fundamental properties such as addition formula, explicit formula, implicit summation formulae, and derivative and integral formulas. Moreover, we establish the relationship between these polynomials with multi-poly-Bernoulli polynomials.

1. INTRODUCTION

The classical Genocchi polynomials $G_n(x)$ (see [3]), the classical Euler polynomials $E_n(x)$ (see [1]), the classical Bernoulli polynomials $B_n(x)$ (see [2]) are defined by the generating function

$$\begin{aligned}\sum_{n=0}^{\infty} G_n(x) \frac{t^n}{n!} &= \frac{2t}{e^t - 1} e^{xt}, \\ \sum_{n=0}^{\infty} E_n(x) \frac{t^n}{n!} &= \frac{2}{e^t - 1} e^{xt}, \\ \sum_{n=0}^{\infty} B_n(x) \frac{t^n}{n!} &= \frac{t}{e^t - 1} e^{xt}\end{aligned}$$

where when $x = 0$, yield $B_n(0) = B_n$, $E_n(0) = E_n$ and $G_n(0) = G_n$ known as the Bernoulli, Euler, and Genocchi numbers, respectively.

The generalization of classical polynomials are defined by means of the k^{th} polylogarithm function, denoted by $\text{Li}_k(z)$, which satisfy the generating function

$$\text{Li}_k(z) = \sum_{m=1}^{\infty} \frac{z^m}{m^k}$$

In addition for this, generalization of these classical polynomials were introduced and are called poly-Bernoulli(see [6]), poly-Euler(see [9]), and poly-Genocchi polynomials(see [12]), which are defined respectively by

$$\sum_{n=0}^{\infty} B_n^{(k)}(x) \frac{t^n}{n!} = \frac{\text{Li}_k(1 - e^{-t})}{e^t - 1} e^{xt},$$

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$$\sum_{n=0}^{\infty} E_n^{(k)}(x) \frac{t^n}{n!} = \frac{2\text{Li}_k(1 - e^{-t})}{1 + e^t} e^{xt},$$

and

$$\sum_{n=0}^{\infty} G_n^{(k)}(x) \frac{t^n}{n!} = \frac{2\text{Li}_k(1 - e^{-t})}{e^t + 1} e^{xt}$$

In 2014, Kim et. al (see [12]) defined a modified poly-Genocchi polynomials denoted by $G_{n,2}^{(k)}(x)$, a generalization of Genocchi polynomials and are defined by means of polylogarithm function respectively

$$\frac{\text{Li}_k(1 - e^{-2t})}{e^t + 1} e^{xt} = \sum_{n=0}^{\infty} G_{n,2}^{(k)}(x) \frac{t^n}{n!}.$$

When $x = 0$, $G_{n,2}^{(k)}(0) = G_{n,2}^{(k)}$ are called the modified poly-Genocchi numbers. By motivation of the definition of poly-Genocchi and modified poly-Genocchi polynomials, in 2017, Kurt (see [5]) introduced the two forms of generalized poly-Genocchi polynomials with parameters a, b , and c given by

$$\begin{aligned} \frac{2\text{Li}_k(1 - (ab)^{-t})}{a^{-t} + b^t} c^{xt} &= \sum_{n=0}^{\infty} G_n^{(k)}(x; a, b, c) \frac{t^n}{n!} \\ \frac{2\text{Li}_k(1 - (ab)^{-2t})}{a^{-t} + b^t} c^{xt} &= \sum_{n=0}^{\infty} G_{n,2}^{(k)}(x; a, b, c) \frac{t^n}{n!}. \end{aligned}$$

In 2016, W. Khan (see [10]) who made interest in studying these polynomials and introduced a Hermite-based generalization of Genocchi polynomials called the Hermite-poly-Genocchi polynomials, denoted by ${}_H G_n^{(k)}(x, y)$ which are defined by k^{th} polylogarithm function as follows

$$\frac{2\text{Li}_k(1 - e^{-t})}{e^t - 1} e^{xt+yt^2} = \sum_{n=0}^{\infty} {}_H G_n^{(k)}(x, y) \frac{t^n}{n!}.$$

And recently, Corcino et. al. (see [7]) introduced a generalization of modified poly-Genocchi polynomials using the concept of multiple polylogarithm called the multi poly-Genocchi polynomials with parameters a, b , and c given by

$$\sum_{n=0}^{\infty} G_n^{(k_1, k_2, \dots, k_r)}(x; a, b, c) \frac{t^n}{n!} = \frac{\text{Li}_{(k_1, k_2, \dots, k_r)}(1 - (ab)^{-2t})}{(a^{-t} + b^t)^r} c^{rxt},$$

where $k_1, k_2, \dots, k_r$ are positive integers and the multiple polylogarithm function satisfy the generating function

$$\text{Li}_{k_1, k_2, k_3, \dots, k_r}(z) = \sum_{0 \leq m_1 \leq m_2 \leq \dots \leq m_r} \frac{z^{m_r}}{m_1^{k_1} m_2^{k_2} \dots m_r^{k_r}}.$$

This paper intends to establish a generalization of Hermite-based multi-poly-Genocchi polynomials with parameters a, b , and c , investigate its relationship with other polynomials, and obtain some fundamental properties.

2. ON HERMITE-BASED MULTI-POLY-GENOCCHI POLYNOMIALS WITH PARAMETERS a, b , AND c

In this section, using the concept of multiple polylogarithm, we introduce the hermite-based multi-poly-Genocchi polynomials with parameters a, b and c .

Definition 2.1. The *Hermite-based multi-poly-Genocchi polynomials with parameters a, b , and c* are defined, respectively, by means of the generating function:

$$(2.1) \quad \sum_{n=0}^{\infty} {}_H G_n^{(k_1, k_2, \dots, k_r)}(x, y; a, b, c) \frac{t^n}{n!} = \frac{\text{Li}_{(k_1, k_2, \dots, k_r)}(1 - (ab)^{-2t})}{(a^{-t} + b^t)^r} c^{rxt+ryt^2}$$

When $y = 0$, Equation (2.1) reduces to multi-poly-Genocchi polynomials with parameters a , b , and c (see [7]).

$$(2.2) \quad \frac{\text{Li}_{(k_1, k_2, \dots, k_r)}(1 - (ab)^{-2t})}{(a^{-t} + b^t)^r} c^{rxt} = \sum_{n=0}^{\infty} \mathcal{G}_n^{(k_1, k_2, \dots, k_r)}(x; a, b, c) \frac{t^n}{n!}.$$

If we put $y = 0$ and $r = 1$, Equation (2.1) reduces to modified poly-Genocchi polynomials with parameters a , b , and c .

$$(2.3) \quad \frac{\text{Li}_k(1 - (ab)^{-2t})}{(a^{-t} + b^t)} c^{xt} = \sum_{n=0}^{\infty} \mathcal{G}_n^{(k)}(x; a, b, c) \frac{t^n}{n!}.$$

Furthermore, if we put $y = 0$, $a = r = 1$, and $b = c = e$ (2.1), we obtain modified poly-Genocchi polynomials (see [12])

$$(2.4) \quad \frac{\text{Li}_k(1 - (1(e))^{-2t})}{(1^{-t} + e^t)} e^{xt} = \sum_{n=0}^{\infty} G_n^{(k)}(x) \frac{t^n}{n!}.$$

When $k = 1$, we obtain the ordinary genocchi polynomials. And when $x = 0$ it reduces to genocchi numbers (see [3]).

Theorem 2.2. Let $a, b, c > 0$. Then for $x, y \in \mathbb{R}$ and $n \geq 0$, we have

$$(2.5) \quad {}_H\mathcal{G}_n^{(k_1, k_2, \dots, k_r)}(x + u, y + z; a, b, c) = \sum_{j=0}^{\lfloor \frac{n}{2} \rfloor} \sum_{m=0}^{n-2j} \frac{n!}{j!(n-m-2j)!m!} {}_H\mathcal{G}_{n-m-2j}^{(k_1, k_2, \dots, k_r)} u^m z^j (r \ln c)^{m+j},$$

$$(2.6) \quad {}_H\mathcal{G}_n^{(k_1, k_2, \dots, k_r)}(x + u, y + z; a, b, c) = \sum_{m=0}^n \binom{n}{m} {}_H\mathcal{G}_{n-m}^{(k_1, k_2, \dots, k_r)}(x, y; a, b, c) H_m(ru, rz; c),$$

$$(2.7) \quad {}_H\mathcal{G}_n^{(k_1, k_2, \dots, k_r)}(x + y, z; a, b, c) = \sum_{m=0}^n \binom{n}{m} {}_H\mathcal{G}_{n-m}^{(k_1, k_2, \dots, k_r)}(x, z; a, b, c) y^m (r \ln c)^m.$$

Proof. Using Definition (2.1)

$$\begin{aligned} & \sum_{n=0}^{\infty} {}_H\mathcal{G}_n^{(k_1, k_2, \dots, k_r)}(x + u, y + z; a, b, c) \frac{t^n}{n!} \\ &= \frac{\text{Li}_{(k_1, k_2, \dots, k_r)}(1 - (ab)^{-2t})}{(a^{-t} + b^t)^r} c^{r(x+u)t + r(y+z)t^2} \\ &= \sum_{j=0}^{\lfloor \frac{n}{2} \rfloor} \sum_{m=0}^{n-2j} \frac{n!}{m!j!(n-m-2j)!} {}_H\mathcal{G}_{n-m-2j}^{(k_1, k_2, \dots, k_r)}(x, y; a, b, c) (ru \ln c)^m (rz \ln c)^j \end{aligned}$$

Comparing the coefficients of $\frac{t^n}{n!}$ gives (2.5). □

The proofs for (2.6) and (2.7) will proceed in the same manner as the proof for (2.5).

Corollary 2.3. The generalized hermite-based multi-poly-Genocchi polynomials with parameters a , b , and c satisfy the following formula

$${}_H\mathcal{G}_n^{(k_1, k_2, \dots, k_r)}(x + y, z; a, b, c) = \sum_{m=0}^n \binom{n}{m} x^m (r \ln c)^m {}_H\mathcal{G}_{n-m}^{(k_1, k_2, \dots, k_r)}(y, z; a, b, c).$$

Theorem 2.4. *The Hermite-based multi-poly-Genocchi polynomials with parameters a, b , and c , satisfy the following explicit formulae stated below.*

$$\begin{aligned} {}_H\mathcal{G}_n^{(k_1, k_2, \dots, k_r)}(x, y; a, b, c) &= \sum_{m=0}^{\lfloor \frac{n}{2} \rfloor} \frac{n!}{m!(n-2m)!} \mathcal{G}_{n-2m}^{(k_1, k_2, \dots, k_r)}(x; a, b, c) y^m (r \ln c)^m \\ {}_H\mathcal{G}_n^{(k_1, k_2, \dots, k_r)}(x, y; a, b, c) &= \sum_{i=0}^n \sum_{m=0}^{\lfloor \frac{n-i}{2} \rfloor} \sum_{\substack{0 \leq m_1 \leq m_2 \leq \dots \leq m_r \\ c_1 + c_2 + c_3 + \dots = r}} \sum_{j=0}^{m_r} \frac{n!}{m! i! (n-2m-i)!} \\ &\quad \frac{(-1)^{j+c_1+2c_2+\dots} (rx \ln c - 2j \ln ab)^{n-2m-i} \binom{m_r}{j} (ry \ln c)^{m_r} (r \ln a + (c_1 + 2c_2 + \dots) \ln ab)^i}{(c_1! c_2! \dots) (m_1^{k_1} m_2^{k_2} \dots m_r^{k_r})} \end{aligned}$$

Theorem 2.5. *The Hermite-based multi-poly-Genocchi polynomials with parameters a, b , and c , satisfy the formula*

$${}_H\mathcal{G}_{l+p}^{(k_1, k_2, \dots, k_r)}(z, y; a, b, c) = \sum_{m, n=0}^{l, p} \binom{l}{m} \binom{p}{n} r^{m+n} (\ln c)^{m+n} (z-x)^{m+n} {}_H\mathcal{G}_{l+p-m-n}^{(k_1, k_2, \dots, k_r)}(x, y; a, b, c)$$

Proof. Replacing t by $t+u$ in Definition 2.3, we have

$$\begin{aligned} \frac{\text{Li}_{(k_1, k_2, \dots, k_r)}(1 - (ab)^{-2(t+u)})}{(a^{-(t+u)} + b^{t+u})^r} e^{rx(t+u) + ry(t+u)^2} &= \sum_{l=0}^{\infty} {}_H\mathcal{G}_l^{(k_1, k_2, \dots, k_r)} \sum_{p=0}^l \frac{t^{l-p} u^p}{(l-p)! p!} \\ &= \sum_{l, p=0}^{\infty} {}_H\mathcal{G}_{l+p}^{(k_1, k_2, \dots, k_r)}(x, y; a, b, c) \frac{t^l}{l!} \frac{u^p}{p!} \end{aligned}$$

Multiplying both sides of equation above by $e^{r(z-x)(t+u)}$, we get

$$e^{r(z-x)(t+u)} \sum_{l, p=0}^{\infty} {}_H\mathcal{G}_{l+p}^{(k_1, k_2, \dots, k_r)}(x, y; a, b, c) \frac{t^l}{l!} \frac{u^p}{p!} = \sum_{l, p=0}^{\infty} {}_H\mathcal{G}_{l+p}^{(k_1, k_2, \dots, k_r)}(z, y; a, b, c) \frac{t^l}{l!} \frac{u^p}{p!}$$

It follows that

$$\begin{aligned} \sum_{l, p=0}^{\infty} {}_H\mathcal{G}_{l+p}^{(k_1, k_2, \dots, k_r)}(z, y; a, b, c) \frac{t^l}{l!} \frac{u^p}{p!} &= \sum_{m, n=0}^{\infty} \sum_{l, p=0}^{\infty} r^{m+n} (\ln c)^{m+n} (z-x)^{m+n} \frac{t^m}{m!} \frac{u^n}{n!} {}_H\mathcal{G}_{l+p}^{(k_1, k_2, \dots, k_r)}(x, y; a, b, c) \frac{t^l}{l!} \frac{u^p}{p!} \\ &= \sum_{m, n=0}^{l, p} \binom{l}{m} \binom{p}{n} r^{m+n} (\ln c)^{m+n} (z-x)^{m+n} {}_H\mathcal{G}_{l+p-m-n}^{(k_1, k_2, \dots, k_r)}(x, y; a, b, c). \end{aligned}$$

Comparing the coefficients of $\frac{t^n}{n!}$, the desired result is obtained. $\square$

Lemma 2.6. *The Hermite-based multi-poly-Genocchi polynomials with parameters a, b , and c , satisfy the formula*

$$\mathcal{G}_n^{(k_1, k_2, \dots, k_r)}(x+1; a, b, c) = \mathcal{G}_n^{(k_1, k_2, \dots, k_r)}(x; ac, \frac{b}{c}, c)$$

Theorem 2.7. *The Hermite-based multi-poly-Genocchi polynomials with parameters a, b , and c , satisfy the following implicit formula*

$$\sum_{n=0}^{\infty} {}_H\mathcal{G}_n^{(k_1, k_2, \dots, k_r)}(x+1, y; a, b, c) = \sum_{j=0}^{\lfloor \frac{n}{2} \rfloor} y^j (r \ln c)^j \frac{n!}{j!(n-2j)!} \mathcal{G}_{n-2j}^{(k_1, k_2, \dots, k_r)}(x; ac, \frac{b}{c}, c),$$

$${}_H\mathcal{G}_n^{(k_1, k_2, \dots, k_r)}(x, y; a, b, c) = \sum_{m=0}^{n-2j} \sum_{j=0}^{\lfloor \frac{n}{2} \rfloor} \frac{n!}{m!j!(n-2j-m)!} y^j x^{n-m-2j} (r \ln c)^{n-m-j} \mathcal{G}_n^{(k_1, k_2, \dots, k_r)},$$

$${}_H\mathcal{G}_n^{(k_1, k_2, \dots, k_r)}(x+1, y; a, b, c) = \sum_{m=0}^n \binom{n}{m} (r \ln c)^{n-m} {}_H\mathcal{G}_m^{(k_1, k_2, \dots, k_r)}(x, y; a, b, c).$$

Theorem 2.8. Each of the following formula holds:

$$\frac{\partial}{\partial x} {}_H\mathcal{G}_n^{(k_1, k_2, \dots, k_r)}(x, y; a, b, c) = (n+1)(r \ln c) {}_H\mathcal{G}_{n+1}^{(k_1, k_2, \dots, k_r)}(x, y; a, b, c)$$

$$\frac{\partial}{\partial y} {}_H\mathcal{G}_n^{(k_1, k_2, \dots, k_r)}(x, y; a, b, c) = (n+1)(n+2)(r \ln c) {}_H\mathcal{G}_{n+2}^{(k_1, k_2, \dots, k_r)}(x, y; a, b, c)$$

Theorem 2.9. The following formula holds:

$$\int_r^s {}_H\mathcal{G}_n^{(k_1, k_2, \dots, k_r)}(x, y; a, b, c) = \frac{{}_H\mathcal{G}_{n+1}^{(k_1, k_2, \dots, k_r)}(x, y; a, b, c)(s, y) - {}_H\mathcal{G}_{n+1}^{(k_1, k_2, \dots, k_r)}(x, y; a, b, c)(r, y)}{(n+1)(r \ln c)}$$

$$\int_\lambda^\mu {}_H\mathcal{G}_n^{(k_1, k_2, \dots, k_r)}(x, y; a, b, c) = \frac{{}_H\mathcal{G}_{n+2}^{(k_1, k_2, \dots, k_r)}(x, y; a, b, c)(x, \mu) - {}_H\mathcal{G}_{n+2}^{(k_1, k_2, \dots, k_r)}(x, y; a, b, c)(x, \lambda)}{(n+1)(n+2)(r \ln c)}$$

3. RELATION BETWEEN HERMITE-BASED MULTI-POLY-GENOCCHI POLYNOMIALS WITH PARAMETERS a, b AND c AND MULTI-POLY-BERNOULLI POLYNOMIALS

In this section, we obtain relation between Hermite-based multi-poly-Genocchi polynomials with parameters a, b and c ${}_H\mathcal{G}_n^{(k_1, k_2, \dots, k_r)}(x, y; a, b, c)$ and multi-poly-Bernoulli polynomials $\mathcal{B}_n^{(k_1, k_2, \dots, k_r)}(x; a, b, c)$.

Theorem 3.1. The Hermite-based multi-poly-Genocchi polynomials with parameters a, b and c satisfy the relation.

$${}_H\mathcal{G}_n^{(k_1, k_2, \dots, k_r)}(x, y; a, b, c) = \sum_{j=0}^{\lfloor \frac{n}{2} \rfloor} \sum_{m=0}^r \binom{r}{m} (-1)^m \frac{n!}{j!(n-2j)!} \mathcal{B}_{n-2j}^{(k_1, k_2, \dots, k_r)} \times$$

$$\left(\frac{rx \ln c - (r+m) \ln b - m \ln a}{2(\ln a + \ln b)} \right) 2^{n-2j} (\ln a + \ln b)^{n-2j} (ry \ln c)^j$$

Proof. Rewriting the right hand side of Definition (2.1) and applying Binomial Theorem

$${}_H\mathcal{G}_n^{(k_1, k_2, \dots, k_r)}(x, y; a, b, c)$$

$$= \frac{\text{Li}_{(k_1, k_2, \dots, k_r)}(1 - (ab)^{-2t})}{(a^{-t} + b^t)^r} c^{rxt+ryt^2}$$

$$= \frac{\text{Li}_{(k_1, k_2, \dots, k_r)}(1 - (ab)^{-2t})(1 - (ab)^{-t})^r}{(1 - (ab)^{-2t})^r b^{rt}} c^{rxt+ryt^2}$$

Using exponential and logarithmic function, we have

$$\frac{\text{Li}_{(k_1, k_2, \dots, k_r)}(1 - (ab)^{-2t})}{(a^{-t} + b^t)^r} c^{rxt+ryt^2} = \frac{\text{Li}_{(k_1, k_2, \dots, k_r)}(1 - e^{-2t(\ln ab)})}{(1 - e^{-2t(\ln ab)})^r} e^{rxt \ln c} e^{-2rt \ln b} \times$$

$$\times (e^{t \ln b} - e^{-t \ln a})^r e^{ryt^2 \ln c}$$

$$= \frac{\text{Li}_{(k_1, k_2, \dots, k_r)}(1 - e^{-2t(\ln ab)})}{(1 - e^{-2t(\ln ab)})^r} \sum_{m=0}^r \binom{r}{m} (-1)^m e^{(t \ln b)r-m} \times$$

$$\times e^{(-t \ln a)m} e^{rxt \ln c} e^{-2rt \ln b} e^{ryt^2 \ln c}$$

Furthermore,

$$\begin{aligned}
 & \sum_{n=0}^{\infty} {}_H\mathcal{G}_n^{(k_1, k_2, \dots, k_r)}(x, y; a, b, c) \frac{t^n}{n!} \\
 &= \sum_{n=0}^{\infty} \sum_{j=0}^{\lfloor \frac{n}{2} \rfloor} \sum_{m=0}^r \binom{r}{m} (-1)^m \mathcal{B}_{n-2j}^{(k_1, k_2, \dots, k_r)} \left(\frac{rx \ln c + (r-m) \ln b - m \ln a}{2(\ln a + \ln b)} \right) \\
 &\quad \times 2^{n-2j} (\ln a + \ln b)^{n-2j} (ry \ln c)^j \frac{n!}{n!} \frac{t^{n-2j}}{(n-2j)!} \frac{t^{2j}}{j!} \\
 &= \sum_{j=0}^{\lfloor \frac{n}{2} \rfloor} \sum_{m=0}^r \binom{r}{m} (-1)^m \frac{n!}{j!(n-2j)!} \mathcal{B}_{n-2j}^{(k_1, k_2, \dots, k_r)} \\
 &\quad \times \left(\frac{rx \ln c + (r-m) \ln b - m \ln a}{2(\ln a + \ln b)} \right) \times 2^{n-2j} (\ln a + \ln b)^{n-2j} (ry \ln c)^j
 \end{aligned}$$

Comparing the coefficients of $\frac{t^n}{n!}$ gives (3.1). □

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